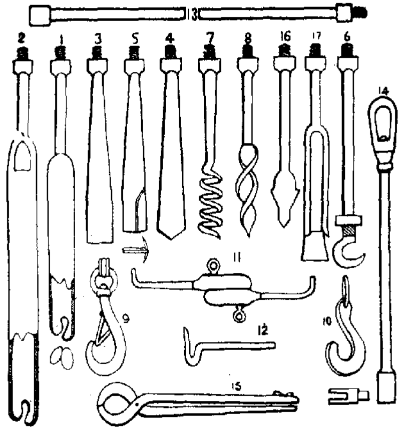
Boring Tools.

LARGE STOCKS KEPT.



All our Boring Tools are manufactured from the best materials and are specially designed to meet the various duties they may be called upon to perform.

ESTIMATES SUBMITTED FOR COMPLETE SETS FOR BORING TO VARIOUS DEPTHS.

Abyssinian Tube Wells a speciality.

Write for Lists.

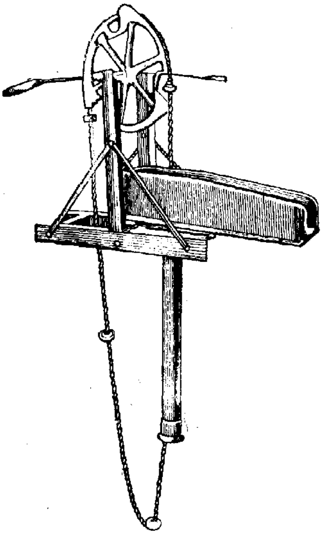
BURN & CO. LTD

HOWRAH & CALCUTTA.

Empire Engineering

Limited,

CAWNPORE.



The most up-to-date Engineering W
Upper India.

For Irrigation and Municipal manufactures
Awarded Gold and Silver Medals
Allahabad and Lahore Exhibiti
in competition with every firm in I

Power Pumps driven by Oil or Steam I

Estimates for Complete Pumping Plants on a

General arrangement of bore tube sinking by the water jet system.

FURTHER NOTES ON

TUBE WELLS

BORING, SINKING AND WORKING

FOR

IRRIGATION PURPOSES AND
PUBLIC WATER SUPPLIES

BY

T. A. MILLER BROWNLIE, C.E.

SECOND EDITION

CALCUTTA & SIMLA

THACKER, SPINK & CO

1914

PRINTED BY
THACKER, SPINK & CO., CALCUTTA.

PREFACE TO SECOND EDITION.

SINCE the publication, more than eighteen months ago, of my Notes on Tube Wells in Theory and in Practice, many Engineers have asked me to describe various methods of boring and pumping systems which may be adopted to suit the convoluted Tube Well.

In these notes I have endeavoured to meet the requirements of those who are interested in Tube Well water supplies and to describe methods of boring which may easily be carried out by practically untrained labourers. Deep boring in hard subsoils, as required more frequently in oil mining, has not been fully described as this class of work is required more generally for Artesian water supplies than for Tube Well supplies.

Various types of pumping plant are described and illustrated, but local conditions must in all cases be carefully considered and the plant selected which will prove most suitable for those conditions and economical in running cost.

I have to acknowledge with thanks the assistance given to me by Messrs. The Worthington Pump Co. for particulars and data regarding the Air Lift system of pumping; to Messrs. Reaveal & Co. for illustrations of vertical high speed paraffin engines, etc.; to Messrs. Jessop & Co.

for illustrations of boring tools, etc.; and to Messrs. Glenfield & Kennedy, Ld., for particulars and illustrations of Ashley's patent deep well pump.

T. A. MILLER BROWNLIE.

September 1913.

PREFACE TO FIRST EDITION.

It is not so many years since Engineers when requiring to determine the yield of an ordinary well, pumped, or otherwise lowered the water level in the well to any extent, usually limited to the power of the pumping plant available, the yield was then calculated from the rate of recuperation, or the discharge of the pump.

In most cases the discharges thus obtained are many times higher than the wells would yield under a constant demand, and if taxed to the thus estimated yield, would, in a very short time, silt, or choke up.

The Hon'ble Mr. J. T. Farrant, late Chief Engineer, Punjab Public Works Department, was, I believe, the first Engineer to establish, and reduce to formulæ, the theory of critical velocities for ordinary wells. By these formulæ, the safe yield of any proposed well can be accurately determined, the nature of the subsoil being known.

It occurred to me that Tube Wells for large discharges of water, free from sand, could be made, if designed to work within this recognised critical velocity of water passing through fine sand, and with this object in view, experiments extending over several years have been carried out.

As a result of these experiments, convoluted Tube Wells have been made on this principle, and have been proved to fulfil all the conditions for which they are designed.

The adoption of convoluted Tube Wells for public water supplies has been recommended by the Sanitary Engineer to Government, Punjab, who reports that " the benefits to the Province at large which will accrue from the proved success of the experiments, will be great."

The following notes, although far from complete, will, I hope, be useful to those interested in Tube Wells.

T. A. MILLER BROWNLIE.

AMRITSAR:
February 1912.

CONTENTS.

ABYSSINIAN TUBE WELLS.

UNTIL recently, tube wells were employed to draw only comparatively small quantities of water from the subsoil, the type familiar to most people is the Abyssinian pattern. This consists of a short length of four or five feet of one and a quarter or one and a half inches diameter wrought iron tube, perforated with small holes and having wrapped round it a layer of fine copper or brass gauze to act as a straining material; over this, as a protection to the gauze, a layer of perforated thin sheet metal is secured. One end of this straining tube is provided with a steel driving point and the other end is connected to a length of plain wrought iron tube. The tube well thus formed is driven vertically into the ground and a hand pump is attached to the upper end of the plain tube.

When water is pumped from the Abyssinian tube well there is at first a considerable quantity of fine sand delivered with the water and if pumping is continued the flow of water will gradually diminish and probably cease altogether. This stoppage of flow is caused by the comparatively high velocity of water through the straining material, bringing with it the finer particles of sand, some of which pack up on the outside of the straining material forming an almost impermeable "conglomerate," the remainder pass through the straining material and are carried up to the pump, but, as packing round the straining material increases the velocity is insufficient to carry the particles to the pump and they settle at the bottom of the tube well, gradually closing up the inside of the strainer.

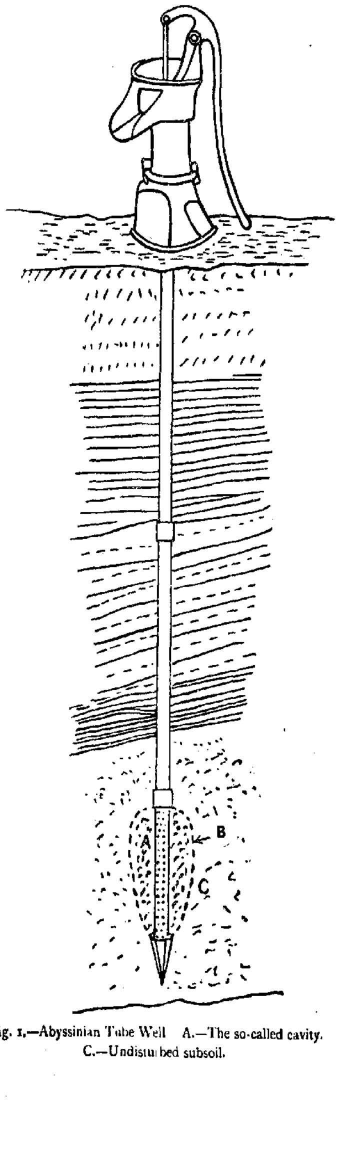


Fig. 1.—Abyssinian Tube Well A.—The so-called cavity.
C.—Undisturbed subsoil.

In order to obtain a constant supply of water from these tube wells they require to be "educated up" to the demand to be made on them. On the first sign of diminution of supply, the pump plunger should be operated to allow air to pass below it and suddenly release the head caused by the vacuum due to pumping, thus a reverse flow through the strainer is caused which displaces the finer particles of sand and on again pumping, these are carried through the strainer up to the pump. By repeating this operation several times the sand surrounding the strainer is washed of its finer particles, and a pear-shaped cavity of coarse sand is formed round the strainer. When this stage is reached the tube well is giving its best results and any more convenient form of pump may be substituted for the "sinking" pump; it must, however, be noted that the power of the pump should remain the same as that used for sinking. If a more powerful pump is employed, then the coarse sand cavity is enlarged owing to the increased velocity through the strainer carrying more of the fine sand into the tube, and the clearing operations have to be again performed until the subsoil surrounding the strainer adapts itself to the new conditions imposed by the higher power of pump.

Fig. I shows the Abyssinian tube well and the approximate shape of cavity formed round the short strainer, this so-called cavity is only a cavity in the sense that it does not contain the finer grains of sand.

The dotted line B, Fig. I, represents the point of change from the ordinary stratum to the washed sand free from fine grains surrounding the strainer. The cubic capacity of this cavity can be calculated as its superficial area is such that the water pumped passes through this surface at a velocity of from half an inch per minute to three-quarters of an inch per minute; these velocities being the critical velocities for sandy and clayey soils

therefore, if the stratum is known the size of cavity can be fairly accurately computed.

Experiments with Abyssinian tube wells show that when pumping is carried on at a rate which represents a velocity through the strainer of half an inch to one inch per second, the well will yield a constant supply of water free from sand; with velocities above one inch per second, traces of sand are frequently found in the water, and in strata where sand is fine, velocities of two and three inches per second will absolutely choke up the tube well.

This type of tube well is of course limited to comparatively small supplies, five gallons to fourteen gallons per minute, or say up to 800 gallons per hour, large tubes cannot be driven into the ground as they are liable to split and the fact that the gauze straining material is placed in contact with the perforated tube reduces the waterway area by seventy-five per cent., that proportion being taken up by the wires forming the gauze. Owing to the fineness of the wires necessary in a small mesh gauze, the straining material is extremely perishable and requires renewal on an average, every two years.

COOK'S TUBE WELL.

THE American patent tube well, known as "Cook's Tube," has been in use for a number of years, and the sizes commonly in use are for discharges of seven to eight thousand gallons per hour.

This tube well consists of a plain brass tube having throughout its entire length, and at intervals of approximately one-fifth inch, circumferential slots about one inch in length, for general purposes a width of slot of one hundredth part of an inch is suitable; the metal at the edges of the slots is bevelled off on the inside of the tube, in order to allow grains of sand which are

carried up to the slot during the clearing operations, passing easily through into the tube, instead of packing against the outside and partially closing the slot. Fig. 2 shows the arrangement and shape of slots employed. Supposing a tube well is required for a supply of 5,000 gallons per hour, and the subsoil water level is not to be reduced at the tube more than five feet, then by Weisbach's formula a three-inch pipe delivering 5,000 gallons per hour will absorb 2·9 feet in friction in a length of 100 feet, the velocity in the tube being 4·5 feet per second. In a three-inch pipe one inch long there will be 45 slots, each $\frac{3}{4}$ inch long, and say one hundredth of an inch wide; then for a velocity of 1 inch per second through the slots, the total area of slots would require to be; area in square feet $= \frac{\text{discharge in cubic feet per second}}{\text{mean velocity in feet per second}} = \frac{0{\cdot}22}{0{\cdot}08} = 2{\cdot}75$, and 2·75 square feet represents a tube length of 98 feet.

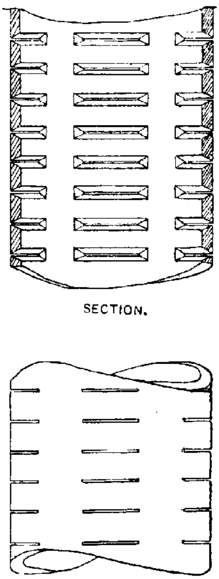


Fig. 2.—Cook's Tube Well.

A greater velocity than one inch per second would result in packing of the sand particles against the slots at the upper end of the tube where the suction effect is greatest and the slots would be gradually closed up, resulting in a higher velocity through the remaining slots, and consequently hastening the closing of these also; as the closing of the slots is in progress the finer particles are passing

more rapidly through the slots, and the proportion of fine sand to water becomes such, that the interior of the tube also is closed, and requires to be washed out before pumping can be continued. The experiments made with this type confirm the assumption that, with tube wells the critical velocity is between half an inch and one inch per second, or say sixty times the critical velocity in open wells. The Cook's tube is perfectly suited for moderate supplies, but being somewhat difficult to slot, is expensive.

TUBE WELL AT LAHORE.*

IN 1909 a tube well was sunk at Lahore; this consisted of 40 feet of $4\frac{1}{2}$ inches diameter wrought iron pipe perforated with holes, the total area of the holes amounted to 14·1 square feet in the 40 feet length of tube. This tube, the metal of which was $\frac{3}{16}$ths inch thick, was wound with a spiral of brass wire, $\frac{1}{8}$ inch diameter, and over this wire fine brass gauze 40 meshes per lineal inch was wrapped. In gauze of this mesh the waterway area is 55 square inches per square foot, and as the diameter covered by gauze was $5\frac{1}{8}$ inches, therefore, in the length of 40 feet there were 68·76 square feet of gauze having 26·26 square feet of waterway area, or almost twice the area of holes in the tube.

The change in velocity of water passing through the gauze, and thence through the holes, caused by this great difference in waterway area, produces eddies in the tube, and diminishes to a very large extent the discharge. This tube well under a head of 7 feet discharged 3,000 gallons per hour or 8 cubic feet per minute, the actual head absorbed in pipe friction being 0·3 foot

* *Vide* Punjab Public Works Department paper No. 62, Tube Well Experiments, also paper No. 63, Notes on the Yield of Wells, by the Hon'ble Mr. J. T. Farrant, Chief Engineer.

and the approximate head absorbed between strainer and perforations being 4 feet.

The velocity through the strainer being greater than the critical velocity in unprotected sand, resulted in a certain amount of sand being brought into the tube which accumulated under the low heads and was disturbed, and carried out of the tube under heads from 10 to 14 feet, when the discharging velocity rose to 2·6 feet per second, that velocity being sufficient to hold most qualities of sand in suspension.

The experiments were of short duration and none appear to have been carried out for more than twenty to thirty minutes at one time, and the constant starting and stopping of the pump at such short intervals is bound to have produced an oscillation in the water column in the tube, the effect of which is exactly similar to that created in the Abyssinian tube well in order to clear the fine sand from the strainer.

With a gauze of 40 spaces to the lineal inch, the safe head would be approximately 7 feet, and if a pump with capacity of 3,000 to 3,500 gallons per hour had been employed constantly for eight or ten hours per day, there is no doubt that all sand would have been removed from the tube in a day or two, and the after discharge would have been steady and free from sand.

The experiments are of interest in so far that they show the loss in discharge caused by the large difference in waterway area of the straining material and perforations.

CRITICAL VELOCITIES FOR ORDINARY WELLS.

Most people are aware that only a limited quantity of water can be taken from any well; this limited quantity which is the safe yield of the well, represents a maximum velocity of water passing through the subsoil (sand, gravel, etc.), which forms the well floor, with-

out disturbing the arrangement of the finest particles forming the flooring.

The velocity at which this disturbance commences is known as the "critical velocity" and this varies with different qualities of subsoil. For instance, in a well sunk in gravel the water passes through this material at a comparatively high velocity before the smallest pebbles are displaced, whereas in a well sunk in sand, the critical velocity is much lower, the finest particles of that material being more readily displaced than small pebbles.

Water may be withdrawn from any well for an indefinite period without damage to the well, provided the critical velocity is not exceeded, but, if the rate of withdrawal of the water exceeds the critical velocity, the effect is as follows:—The finest particles of sand at and near the surface of the floor of the well are the first to be displaced, these will be in partial or full sus-

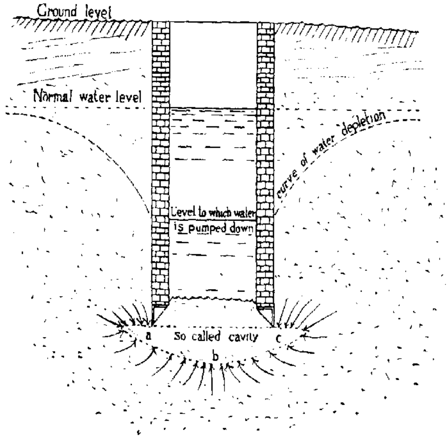


Fig. 3.—Illustrating disturbances and cavity formed under well when critical velocity is exceeded.

pension, according to the velocity of the water; fine particles from the layer below the surface will travel upwards to replace the voids left by the particles from the surface layer, and these in turn will be carried into the well. This action extends below the level of the bottom of the walls or curb of the well and also extends laterally; the fine particles flow in from under the walls, the density of the subsoil is being altered, the spaces between the particles of sand increased.

The disturbance of the subsoil is within a roughly shaped plano-convex figure, on the plane surface of which the well rests, and the superficial area of the whole figure (excluding the well area) is such that the water passes through this surface at the critical velocity for the subsoil. (See Fig. 3.)

What then is the result of exceeding the critical velocity of a well? (*a*) The finest material is washed into the well and forms a new floor in the well above the level of the old floor, *i.e.*, silting occurs. (*b*) The subsoil under the well is loosened and the well tends to sink and is liable to collapse.

Various expedients have been tried in order to increase the yield of wells beyond their critical velocities; one of these is to fill in the floor of the well to a certain depth with gravel of various sizes, arranged somewhat in the manner of a percolation filter, but in reverse order; this has not proved satisfactory, as after a short time the well again becomes silted by sand, etc., being carried up through the interstices of the stones. Exactly the same feature is observed in ordinary water filters when worked too rapidly; when sand of varying grades of coarseness forms the floor surface of wells, it has been found that the fine particles are disturbed at velocities of $2\frac{1}{2}$ feet to 3 feet per hour, *i.e.*, the critical velocity.

Another method is to cover the floor of the well with a fine straining material, and this also has proved unsatisfactory on account of the finest particles of the subsoil being washed through the strainer and silting on its upper surface, while at the same time the coarser particles pack on the underside of the strainer thereby reducing the flow until the yield ultimately falls again to the critical velocity.

Many engineers have endeavoured to increase the yield of wells by sinking the wells deeper than is actually required to provide a suitable depth of water over the mouth of the suction pipe and from the mouth of the suction pipe to the floor of the well. For example, assume that a certain well of 12 feet diameter is sunk to a depth of twenty feet below normal water level and the subsoil at the floor of this well is fine sand having a critical velocity of 3 feet per hour; then the safe maximum yield of the well is A = area of well = 113 sq. feet x 3 feet per hour = 2,119 gallons per hour. Now by sinking this well so as to have a depth of say 40 feet of water in the well, no increase of yield can be expected because the sand at the bottom of the well will still be disturbed if the velocity is increased above 3 feet per hour in spite of the extra depth of water, or, as it is sometimes called, the water cushion. Where an increased yield has been obtained after deepening a well, it has been proved that the well is actually gradually silting up or else by deepening, a coarser and therefore more porous subsoil has been entered, such a subsoil having a higher critical velocity.*

Experiments on the yield of ordinary wells have been carried out for over 30 years by various engineers

---

* See Public Works Department paper No. 178, by Mr. Dawson, Manual of irrigation wells, by Mr. Maloney.

Punjab Public Works Department paper No. 63, Notes on the yield of wells, by the Hon'ble Mr. J. T. Farrant.

in various parts of the world, and the conclusions drawn from these are that, it is unsafe to withdraw water for any length of time at a rate exceeding the critical velocity of the subsoil of the well. The critical velocity in sand of varying degrees of fineness has been found to be between 2½ and 3 feet per hour, but in coarse sand of *uniform* grain a slight increase in this critical velocity has been observed.

CRITICAL VELOCITIES FOR TUBE WELLS.

IN order to find the critical velocities in sand when tube wells are employed, the writer fitted a short length of straining tube horizontally in a tank, one end of the tube discharging through the side wall of the tank.

The tank was then filled with a mixture of fifty per cent. fine sand and fifty per cent. coarse sand, the fine sand being that which would pass through a sieve of 1,600 meshes per square inch, and the coarse sand that which was retained on the same sieve.

The tank was then gently filled with water, spreading plates being used to prevent disturbance of the sand, observations were made of the effect on the sand of various straining velocities; the water level being kept constant at the head under observation. These experiments show that with a velocity of six inches per second through the strainer, the finest sand passes through the strainer and is discharged at the pipe mouth in considerable quantities, the coarser sand packing up on the outside of the strainer, and after a short time blocking up to such an extent, that the flow is considerably reduced, and the velocity from the tube is insufficient to carry off all the fine sand which has passed into it. Similar results, but less marked, were observed on all heads creating velocities down to two and a half inches per second, and on velocities of less than two and a half inches per second, the fine particles of sand close

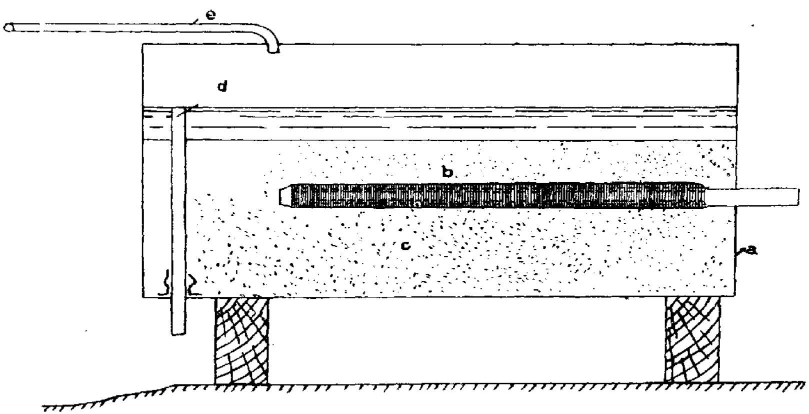


Fig. 4.—(a), Tank; (b), straining tube; (c), mixture of coarse and fine sand, fine sand being dyed red; (d), over-flow pipe which can be raised or lowered; (e), Inlet pipe.

to the strainer were carried through the strainer, and discharged from the tube during the first few minutes of flow, and packing on the outside of the strainer was observed to a slight extent. At velocities of three quarters and half inch per second there was no apparent change in the sand structure surrounding the tube, and only a slight trace of sand was discharged for a few minutes on starting the experiment, after which the water was free from sand.

The conclusions to be drawn from these experiments appear to be that a safe mean velocity for tube wells is half an inch per second, and also that a very fine straining material is unnecessary, provided this velocity is not exceeded, and the diameter of the tube is such that the delivering velocity will be at least three and a half feet per second: this velocity is necessary if the water is to keep in suspension the fine sand passed by the strainer. A most important point which should be observed is, that in clearing the sand surrounding a newly sunk tube, particular care is taken in selecting the clearing tubes, and the depths to which these are lowered. If a tube one half the diameter of the strainer is employed, and lowered more than one half the depth of the strainer at the commencement of clearing, then pumping should be very cautiously carried on or the increase in velocity, and consequently friction, is so great that the water withdrawn will be insufficient to keep the sand in suspension, and the tube well as a whole will become absolutely choked with sand.

When a tube well is made in such a way that the discharging current is in direct contact with the straining material, then the discharging current acts as a blind on the surface of the strainer, and prevents the free passage of water through the strainer. This blinding action takes place whether pumping is done from the

top of the strainer, or the bottom; in the latter case, friction is at least doubled, and the blinding action correspondingly intensified.

Investigations made with a small tube composed of straining material only, show that with an inlet velocity through the straining material of half an inch per second, and a delivering velocity from the tube of approximately three feet per second, the particles of water pass through the strainer, and creep along its inside for a distance which may be as much as quarter of an inch, before they are caught up in the current created by the suction tension. This feature is well known, and the Cook's tube and Smith's well casing are designed with their slots at such a distance apart, that the particles of water passing through one slot have freed themselves from the tube surface, before reaching the next slot. The remedy would appear to be the introduction of an inner perforated tube, having the perforations large enough to prevent blinding and the area of metal sufficient to retain the high velocity current in the inner tube; the water passing through the straining material would then follow the line of least resistance and stream direct to the inner tube, there being caught up in the high velocity current.

A tube well of this form would be considerably shorter for a fixed percolation velocity than a tube well composed of straining material only.

THE THEORETICAL TUBE WELL.

THE observations on the foregoing types of tube wells, and from the experiments on straining tubes and screens, result in the following conclusions.

That the straining material should not be in direct contact with the perforated tube as the area of perforations is thereby reduced by the amount of wire or

other material composing the portions of straining material which are in contact with the perforations.

The straining material should be a certain distance away from the perforated tube, and this distance should be such that the waterway area, in the straining material, is equal to the waterway area in the perforated tube, thus causing no change in velocity between the straining material and the tube.

The critical velocity for tube wells in very fine sand may be taken at half an inch per second, or sixty times greater than for ordinary wells.

The discharging velocity should be not less than three feet per second nor more than five feet per second.*

The superficial area of metal in the perforated tube should be more than twice the area of perforations, in order to prevent eddies or back flow at the perforations.

The straining material should present a maximum amount of waterway area per foot length of tube, consistent with fine openings and heavy wire or other material which will withstand moderately rough handling in transport, and lowering, and will be lasting.

CONVOLUTED TUBE WELL.—(*PATENTED*).

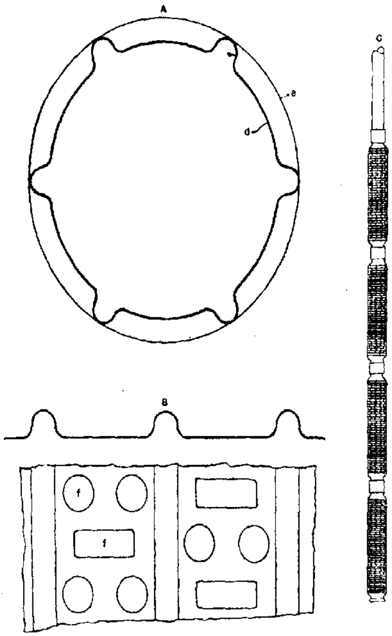
THE writer in designing this form of tube well has endeavoured to meet the above requirements. Fig. 5 shows the general design of this tube which is made of thick sheet steel, is light for transport and easily handled when sinking. The longitudinal convolutions render the tube exceedingly strong and rigid and are made of such a depth that there is no increase in velocity between the straining material and the perforations in the tube.

The proportion between the area of perforations and the area of metal is such that eddies are reduced to a

* This corresponds with the practice of pump manufacturers.

minimum, and "creeping" along the inside of the straining material is also prevented, the discharging current being concentrated, the fine streams of water percolating through the strainer pass straight through the short intervening space, into the main perforated tube.

The straining material consists of heavy copper wires lying parallel, the necessary fine space being maintained by the wires being woven at short intervals,



A.—Cross section of convoluted tube well; (d), body of tube; (e), straining material.

B.—Piece of convoluted sheet before forming into tube; (f), perforations in sheet.

C.—Elevation of convoluted tube well

Fig. 5.

with pairs of fine copper ribbons which prevent slipping, or other alteration of the position of the wires when the tube is handled, or in sinking. This form of straining material has about ten times the life of copper gauze, and is very considerably stronger.

Before the copper straining material is fixed, the tubes are treated to two coats of Callendar's " Kalbitum " as a rust preventative.

Convoluted Tube Wells are made in several sizes for discharges, varying from one quarter to two cusecs, or in other words, from 5,625 to 45,000 gallons per hour; these sizes have been standardized and are all made from the plain sheet on one machine, this resulting in remarkably cheap tube wells.

When used for increasing the supply of water to an ordinary well, the upper end of the " convoluted " tube should have a length of plain tube attached to it; this plain tube should be sufficiently long to project at least two feet above the floor of the well, and the top of the convoluted tube should be not less than ten feet below the floor of the well. In deep wells the plain pipe should project inside the well to not less than seven feet below the normal water-level. There are certain conditions of subsoil when this position of tube well has to be considerably altered, but generally, the above arrangement is satisfactory.

Convoluted Tube Wells are particularly adapted for direct pumping from the tube, and in cases where spring level is near the ground surface, the plain pipe may be used as the suction pipe of the pump. When spring level is at a considerable depth below ground surface, then an alteration has to be made in the plain tube to take a suitable deep well pump.

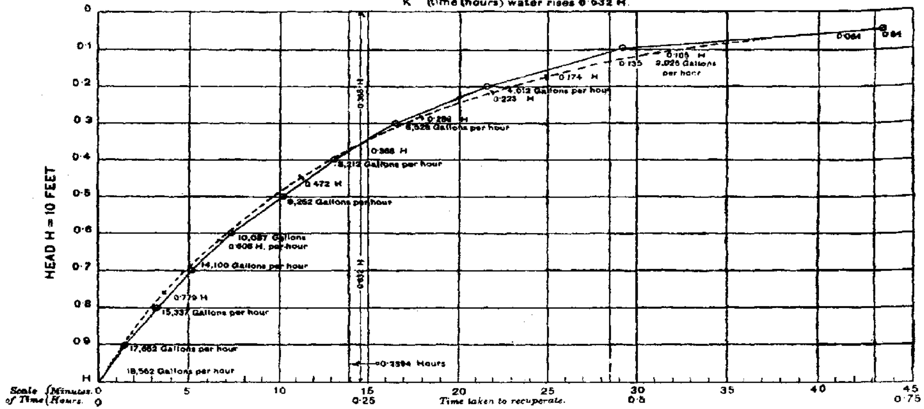
A recuperation curve is shown for a " Convoluted " tube well designed to discharge one half cusecs or 11,250

Fig. 6.

RECUPERATION CURVE FOR 5-INCH CONVOLUTED TUBE WELL.

Note.—The full line shows the recuperation curve plotted from each foot recuperated. The dotted line shows line of theoretical curve calculated from the time constant of the tube.

$t = \frac{A}{K}$ = {time constant / time (hours) water rises 0·632 H.



gallons per hour, when working under a head of seven feet. The actual discharge is approximately twenty per cent. greater than the tube was designed for, and the recuperation curve plotted from the actual discharges under each foot of head practically coincides with the theoretical recuperation curve, plotted from the " time constant."*

The recuperation curve clearly shows that the discharge varies directly as the head, and this well known feature tempts some users of tube wells to increase the head and obtain a larger supply of water. The result of such increase of head is that the critical velocity is exceeded, and the tube well is sooner or later silted up and rendered useless.

Why should a convoluted tube well yield more water than an ordinary well is a question frequently asked, and the reason is that when the tube well is first sunk, and water withdrawn from it, a certain amount of sand comes away with the water, if pumping is continued at the same rate the proportion of sand gradually diminishes until it ceases altogether and a supply of clear water is obtained. What has happened round the strainer of the tube well is that the fine particles of sand have been washed through the straining material into the tube, and the tube being of small bore in comparison to the quantity of water passing through it, the velocity of water up the tube is sufficient to carry the sand with it, keeping the inside of the tube and strainer free from silting. The subsoil surrounding the strainer has become freed of its finer particles, and therefore has a higher porosity than the undisturbed subsoil; this freeing of the subsoil surrounding the strainer takes place within a roughly pear shaped or

* I am indebted to the Hon'ble Mr. J. T. Farrant, late Chief Engineer, Punjab, Public Works Department, for his original formula for the "Time Constant" for recuperation tests.

conical figure, of which the tube well is the axis; the surface area of the figure is such that the water passing through this surface has a velocity not exceeding the critical velocity for the subsoil, therefore surrounding the strainer we have what is usually called the "cavity" and which is only a cavity in the sense that it is freed from the smaller particles of sand and contains the coarser material loosely packed. The writer's experiments have shown that this coarse material arranges itself around the strainer according to size of grain, the largest being next to the strainer, then the second largest and so on, to what might be termed the "critical velocity limit," that is, where the disturbed merges into the undisturbed subsoil.

It is this "critical velocity limit" or surface area of the so-called cavity which must be compared with the ordinary well as the water is passing through it at exactly the same velocity as it would pass through the floor of an ordinary well.

In a tube well designed to discharge 45,000 gallons per hour in moderately fine sand the approximate superficial area of the "critical velocity limit" would be 2,880 square feet, because 45,000 gallons per hour is equal to 2 cubic feet per second, equal to 120 cubic feet per minute; and 120 cubic feet passing through a surface at a rate of half an inch or one twenty-fourth of a foot per hour $= 120 \times 24 = 2{,}880$. An ordinary well in the same subsoil if worked not to exceed the critical velocity of the subsoil would theoretically require to have a floor area of 2,880 feet, that is to say, it would require to be $60\frac{1}{2}$ feet in diameter.

In making the above calculations friction of water passing between the grains of sand situated between the "critical velocity limit" and the tube well, has been neglected, and therefore in actual practice an ordinary

well of between 20 and 25 per cent. less area would suffice to yield 45,000 gallons per hour; say a well of 54 feet diameter.

In estimating the yield from ordinary wells it is customary to allow a considerable margin, for example, although theoretically one large well of 54 feet diameter, or say 20 wells of 12 feet diameter, would yield the required supply, the larger well of 60½ feet or 25 of the smaller wells would in all probability be constructed (in actual practice several small wells would be sunk as that method would be less expensive than sinking the larger well), similarly in estimating the yield from the tube wells a margin of at least 25 per cent. should be allowed for. One advantage in sinking a tube well capable of yielding more than the required supply is that owing to a less quantity of water being taken than the tube is designed for, the water passes through the straining material at a correspondingly lower velocity and therefore the head which is causing the flow through the straining material, is reduced, and a reduction of head means less expense for pumping. This reduction of head or withdrawal of less water that the tube well is designed for should not be carried to extremes. otherwise the upward velocity of water in the tube will be insufficient to hold the sand in suspension.

IRRIGATION FROM CONVOLUTED TUBE WELLS BY PUMPING.*

UNTIL electric power is distributed over areas uncommanded by Canal Irrigation, or over areas which have become water-logged, owing to excessive canal irrigation, and in which it is desired to stop or considerably reduce this system of irrigation and pump water

* I am deeply indebted to the Hon'ble Mr. J. T. Farrant, late Chief Engineer, Punjab, Public Works Department, for the valuable notes he so kindly supplied to me on this subject and on Irrigation by bullock-power.

from the subsoil, liquid fuel must be looked to as the source of power for such purposes.

Various schemes for harnessing the rivers of the Punjab have been prepared from time to time by prominent engineers, but owing to Eastern lack of enterprise those projects appear to have been indefinitely postponed.

From the data given in the projects, and from experience of hydro-electric schemes in other countries, there is not the slightest doubt that electrical energy can be supplied at consumers' terminals at a rate not exceeding one anna per horse power per hour.

That liquid fuel compares not unfavourably with this rate is well known, and experience has shown that oil engines from six to over thirty horse power, can be run on $\frac{3}{4}$ pint low grade kerosine oil, per break horse power, per hour.

For purposes of calculation, one cusec of water raised thirty feet for twenty-four hours, will be taken as the unit, but it should be noted that if two cusecs were taken, then the original cost of pumping plant would be considerably less than double the cost of one cusec plant, consequently depreciation would be less, while attendance would remain the same for both plants.

The horse power required to raise one cusec thirty feet is $\frac{\overset{\text{gallons.}}{6{\cdot}25} \times \overset{\text{lbs.}}{10} \times \overset{\text{secs.}}{60} \times \overset{\text{ft.}}{30}}{33{,}000 \text{ foot pounds}} = 3{\cdot}4$ nett h. p. and with an efficiency of 0·5 for engine and pump, the gross horse power would be 6·8.

The consumption of oil per day is 6·8 B.H.P. × 24 Hrs. × 0·75 Pint = 122·4 pints, and low grade kerosine oil can be purchased in bulk at 9·5 annas per gallon. The cost per day is therefore $\frac{\overset{\text{pints.}}{122{\cdot}4} \times \overset{\text{annas.}}{9{\cdot}5}}{16 \text{ annas} \times 8 \text{ pints}}$ = Rs. 9·084, adding Rs. 0·31 for lubricating oil, etc., and Rs. 0·581 for attention of a

visiting driver at Rs. 18 per month for the one plant, then the total cost is Rs. 9·975, or say Rs. 10 per day of 24 hours.

With electric power at one anna per horse power per hour, and motor and pump efficiency of 0·55, the gross horse power is 6·2 and the daily cost $6{\cdot}2 \times 24 \times \frac{1}{16} =$ Rs. 9·3, *plus* 0·31 for lubrication and half the attention of visiting driver at Rs. 0·29, giving a total of Rs. 9·9, say Rs. 10 per day of 24 hours, in which 86,400 cubic feet of water is pumped.

As one acre contains 43,560 square feet, therefore the cost per acre foot is roughly Rs. 5.

Allowing 75 days for the sowing period of the Rabi crop, and 5 inches in depth for the first watering, and an efficiency factor of $\frac{5}{6}$ths which allows for $\frac{1}{6}$th loss by evaporation and absorption, then the area irrigated to a depth of 5 inches is $75 \times 2 \times \frac{12}{5} \times \frac{5}{6} = 300$ acres.

In the remaining 105 days of the Rabi crop period, 210 acre feet of water are delivered, of which $\frac{5}{6}$ths or 175 acre feet reach the fields, giving them an additional depth of $\frac{175}{300} \times 12 = 7$ inches, or twelve inches in all; which is the amount required.

The cost of pumping for the Rabi crop is therefore, first watering 75 days at Rs. 10 = Rs. 750 for 300 acres, or Rs. 2·5 per acre.

Subsequent waterings 105 days at Rs. 10 = Rs. 1,050 for 300 acres, or Rs. 3·5 per acre.

The total cost per acre being Rs. 6.

For the Kharif crop a total depth of two feet of water is required, and the total crop period being 180 days the area which can be irrigated with an efficiency of $\frac{5}{6}$ths is $180 \times 2 \times \frac{5}{6} \times \frac{1}{2} = 150$ acres. Allowing the first watering 6 inches deep, the period is 45 days, and the cost $45 \times 10 =$ Rs. 450 for 150 acres, or Rs. 3 per acre.

In the remaining 135 days the waterings amount to a depth of 18 inches, and the cost is $135 \times 10 =$ Rs. 1,350, or 150 acres at Rs. 9 per acre.

The total cost per acre being Rs. 12.

The annual cost is therefore, Rabi 300 acres at Rs. 6 per acre = Rs. 1,800, Kharif 150 acres at Rs. 12 per acre = Rs. 1,800, being a total of 450 acres irrigated annually for Rs. 3,600, or an average of Rs. 8 per acre per annum.

A tube well of one cusec delivery, irrigating 450 acres annually, or say 70 per cent. of its commanded area, is sufficient for 640 acres, or one square mile.

The estimated cost of the entire pumping plant is as follows :—

	Rs.†
*Convoluted tube well of 1·25 cusecs capacity..	1,300
Sinking charges	350
Direct coupled oil engine and pump, erected complete	3,450
Engine house	700
Distributing tank, etc.	200
TOTAL ..	6,000

The annual recurring charges would be :—

	Rs.
Interest on Rs. 6,000 at 4 per cent. ..	240
Depreciation of plant at 5 per cent. ..	300
Power, including attention as above ..	3,600
Collection of dues (allow one patwari for two square miles)	135
TOTAL ..	4,275

The average rate which can be charged is therefore Rs. 9-8-0 per acre per annum.

* For subsoils of low porosity a 1·25 cusecs tube is allowed.

† One rupee is equal to one shilling and four pence sterling, *i.e.*, Rs. 15 = £1.

IRRIGATION BY BULLOCK POWER FROM ORDINARY WELLS.

A WELL twelve feet in diameter will yield 2,500 gallons per hour, and when a modern pattern bullock power chain pump is used, one pair of good bullocks will lift 2,400 gallons 30 feet per hour, per day of ten hours (say $\frac{1}{9}$th cusec). Nine-tenths of the water will reach the fields, $\frac{1}{10}$th being evaporation and absorption losses. One pair of bullocks will cost Re. 1 per day.

The area irrigated daily is therefore $\frac{384 \text{ c. ft.} \times 10 \text{ hrs.}}{43{,}560 \text{ sq. ft.}} =$ 0·88, say, $\frac{1}{12}$th acre foot.

For the Rabi crop period of 180 days at 1 foot depth of water, the area irrigated is $180 \times \frac{1}{12} = 15$ acres; and for the Kharif crop period of 180 days at 2 feet depth of water, the area irrigated is $180 \times \frac{1}{24} = 7{\cdot}5$ acres.

The cost of the Rabi crop is therefore $\frac{180 \times 1}{15}$ = Rs. 12 per acre, and the cost for the Kharif crop is $\frac{180 \times 1}{7{\cdot}5}$ = Rs. 24 per acre.

The average cost is therefore $\frac{180 \times 2 \times 1}{22{\cdot}5}$ = Rs. 16 per acre per annum.'

Allowing for depreciation and interest on the bullock pump, then the average cost per acre per annum amounts to Rs. 17·2, or nearly double the cost of irrigation by liquid fuel, or electric power.

TUBE WELLS AS A SOURCE OF PUBLIC WATER-SUPPLY.

FROM A PAPER READ AT SECOND ALL-INDIA SANITARY CONFERENCE, MADRAS, 1912.

IT is unnecessary for me to enter into details of the inadequate and contaminated state of the water supplies of many of the towns and villages in India. Every sanitarian knowns the necessity of a pure water-supply if the health of the people is to be improved.

In order to provide a supply of good water, the wells require to be situated on land free from surface contamination and therefore at some considerable distance from the village, the water being pumped from the wells and delivered to an elevated tank centrally situated in the village, or to ordinary standposts.

A scheme of this type is somewhat costly, necessitating as it does, wells probably sixty to seventy feet in depth, a length of at least half a mile of delivery pipe from the wells to the village and a higher powered engine to overcome the friction in this half mile of pipe.

For villages or small towns where the subsoil water level is within twenty feet of ground surface, the initial cost of a water scheme of this nature would roughly be Rs. 7 per head of population, and the annual maintenance including depreciation and interest 15·47 annas per head of population. Statement "A," page 28, shows how these figures have been arrived at, and although calculated on a supply for a town of 6,000 inhabitants, they are approximately correct for populations between 1,000 and 10,000.

Statement "B," page 29, shows the initial cost of a scheme for supplying this village with the same quantity of water from tube wells; this comes to Rs. 3 per head of population, showing a reduction of 56 per cent. in favour of the tube well scheme. The annual maintenance amounts to 10·2 annas per head of population, being a saving of 33 per cent. over the supply from ordinary wells.

This difference in initial and recurring cost between the two schemes is due to the fact that one medium sized tube well is capable of supplying all the water required, and it can be sunk in the village below contamination level, effecting a further saving of the half

mile of rising main and in the engine power required to overcome the friction in this main.

These savings in initial cost effect the saving of 33 per cent. in annual maintenance as shown in Statement "B," page 29.

Although the tube wells are estimated to last from fifteen to twenty years, no actual test has been made of their lasting capabilities and therefore depreciation at the rate of 20 per cent. has been allowed on the cost of the tube wells, including sinking and necessary masonry work. This permits of the tubes being withdrawn and new ones sunk every five years. It is most unlikely that this sinking fund will require to be utilized, but even if utilized the tube well scheme is still very substantially cheaper both in initial and in recurring cost than the ordinary well supply.

These figures are, I think, sufficient justification for the installation of a tube well water-supply in these towns and villages where the initial and recurring cost of an ordinary well water-supply scheme is prohibitive.

Generally speaking, tube wells may be successfully adopted in any district in which a supply of water is obtainable from ordinary wells, with an average water bearing subsoil the yield of the tube wells manufactured by the Empire Engineering Co., Ld., Cawnpore, varies from five thousand gallons per hour in the 3½-inch tube to forty-five thousand gallons per hour in the 9-inch size.

The question of the relative cost of tube wells is of no great importance when one considers that from an ordinary masonry well twelve feet in diameter as built for modern water supplies, the average yield is roughly 3,000 gallons per hour and the cost is over £200; whereas, at a less cost a tube well can be sunk which will yield 45,000 gallons per hour or fifteen times the supply of an ordinary well and under the same head.

STATEMENT "A."

Rough estimate of cost of a water-supply from ordinary wells for a village of 6,000 inhabitants.

Population 6,000 at 15 gallons per head per day =90,000 gallons, to be pumped in 8 hours = 11,250 gallons per hour, say 190 gallons per minute.

Average wells of 12 feet in diameter may be expected to yield 3,000 gallons per hour, therefore 4 wells are required.

Estimate of cost of scheme.

	Rs.*
Land for 4 wells and engine house 750′×150′= say 2½ acres at Rs. 2,000 per acre ..	5,000
Wells 12 feet diameter 65 feet deep. No. 4 at Rs. 3,500 each	14,000
Suction main 8 inches diameter laid and joined complete, 550 feet at Rs. 3-11-0 per foot, say	2,000
Rising main 6 inches diameter laid and joined complete, 2,640 feet at Rs. 2-6-0 per foot, say	6,300
Engine house 20′ × 12′, plinth say 350 square feet at Rs. 2-4-0 per square foot, say ..	800
Engine and pump to lift 22 feet and force 25 feet, with friction of 13·8 feet in 2,640 feet of rising main, and 3 feet in bends, etc., say 64 feet. H. P. = (190 × 10 × 64) ÷ 33,000 = 3·68 with 0·5 efficiency = 7·36, say 8 B. H. P. No. 2 complete at Rs. 4,000 each ..	8,000
Elevated tank centrally situated in village with all necessary fittings, allow	6,000
Total cost ..	42,100

Maintenance of this scheme.

	Rs.	A.	P.
Oil consumption (8 × 0·75 × 8) ÷ 8 = 6 gallons at 9½ annas	3	9	0
Lubricating oil	0	5	6
Waste and sundry small stores	0	3	6
Starting oil	0	2	0
Driver at Rs. 30 per month	1	0	0
Daily running cost ..	5	4	0

* One rupee is equal to one shilling and four pence sterling, *i.e.*, Rs. 15=£1.

Annual maintenance.

		Rs.
Driving cost Rs. 5-4-0 × 365 = 1917, say	..	1,920
Interest on Rs. 42,100 at 4 per cent.	..	1,684
Depreciation on Rs. 42,100 at 5 per cent.	..	2,105
Total	..	5,700
Allowing for collection and sundries, say	..	5,800

STATEMENT "B."

Rough estimate of cost of a water-supply from Tube Wells for a village of 6,000 inhabitants.

Population of 6,000 at 15 gallons per head per day =90,000 gallons, to be pumped in 8 hours = 11,250 gallons per hour, say 190 gallons per minute.

One 5-inch convoluted tube well will deliver 11,250 gallons per hour, but allow for the tubes being in duplicate.

Estimate of cost of scheme.

		Rs.
Land in village for engine house and tube wells allow 40′ × 12′, or plinth area of 700 square feet	..	100
Convoluted tube well 5 inches diameter, sunk, complete with masonry chambers, etc., No. 2, at Rs. 1,500	..	3,000
Suction main and fittings 140 feet at Rs. 3 per foot	..	420
Rising Main and fittings 100 feet at Rs. 2-6-0 per foot, say	..	240
Engine house, allow 700 square feet at Rs. 2-4-0 square foot, say	..	1,600
Engine and pump to lift 22 feet and force 25 feet with 3 feet friction, total lift = 50 feet H. P. = (190 × 10 × 50) ÷ 33,000 = 2·88, efficiency 0·5 = 5·76 say 6 B. H. P. No. 2, at Rs. 3,500	..	7,000
Elevated tank, centrally situated in village with all necessary fittings, allow..	..	6,000
Total cost ..	..	18,360

a lock ring should first be screwed on the pigot or cressed end of the pipe so that the socket end of the next pipe will butt against this ring when screwed up. It has been proved that this ring increases the strength of the joint by 50 per cent.

Joint No. 3, Fig. 7, has the advantage of offering no resistance externally to the sinking of the tubes and of having the full internal bore at the joint, but it necessitates the tubes being of thicker metal to allow of the joint being made and a finer screw which is difficult to start and liable to damage; tubes with these joints frequently give way at the joint shoulder and it is practically impossible to recess and rescrew the damaged tube at the site of the boring. These tubes are known as the Artesian well bore steel tubes and can be obtained of different weights; for borings up to two or three hundred feet deep a medium thickness of metal will be found sufficient and will last for a large number of borings. With regard to the total length of boring tube required, this depends largely on the depth of water below ground surface; tubing sufficient to sink from ground surface to 120 feet below normal water-level will be required, and it is advisable to have a spare ten feet length or two so that after the tubes have been in use for some time and the joints become damaged or worn, a few inches can be cut from the ends of the tubes and the joints remade.

Cutting Shoe.

In order to render the sinking of the bore tube as easy as possible and to protect the lower edge of the bore tube from damage, a cutting shoe should be used. There are two types of shoes and each has its special advantage. No. 1, Fig. 8, shows the screw type and No. 2, Fig. 8, shows the slip type, both shoes are made from tempered steel and are slightly splayed out at the cutting edge, being

approximately one inch greater diameter at the cutting edge than the external diameter of the bore tube. The

No. 1. No. 2.

Slip Shoe Screw Shoe

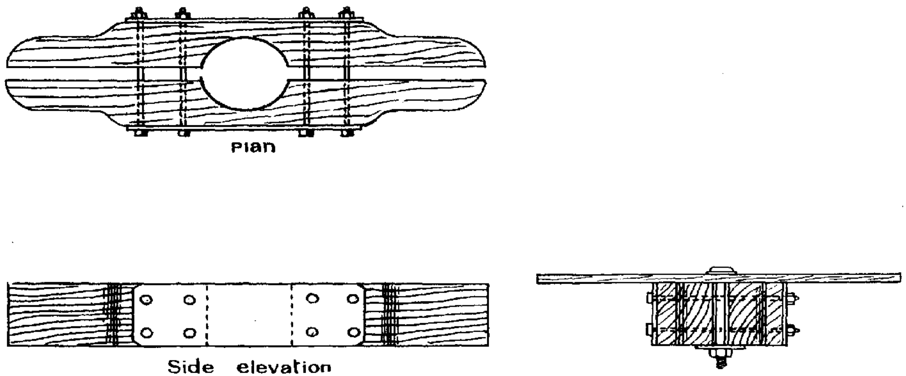
Fig. 8.

screw type of shoe is chiefly used for sandy soils and where the boring does not exceed two to three hundred feet. These soils do not offer much additional friction to withdrawal of the bore tube with the screwed shoe attached, but in stiff clay, rock soils, and for deep borings, the slip shoe is a decided advantage as the shoe clears a hole slightly larger than the bore tube, and this clearance remains open to some extent, thus friction on the tube is reduced both in sinking and in withdrawal ; this type of shoe is, as its name implies, slipped from the bore tube and left at the bottom of the bore when the tube is withdrawn. The cutting shoes are not expensive and the cost of one shoe per boring is amply repaid in the reduced cost of sinking the bore tube.

Starting boring.

The simplest method of starting the bore is to dig a hole eight or ten feet deep, keeping it as small in diameter as convenient, into this hole the first length of bore tube is lowered, having the cutting shoe at the bottom, the bore tube is carefully plumbed and the hole filled up with earth well rammed to hold the bore tube in position. When the boring is to be a deep one it is advisable to sink a much deeper hole for a start, at least thirty feet, and a timber casing is put in this hole,

Details of Wood Clamp.



Plan

Side elevation

Fig. 9.

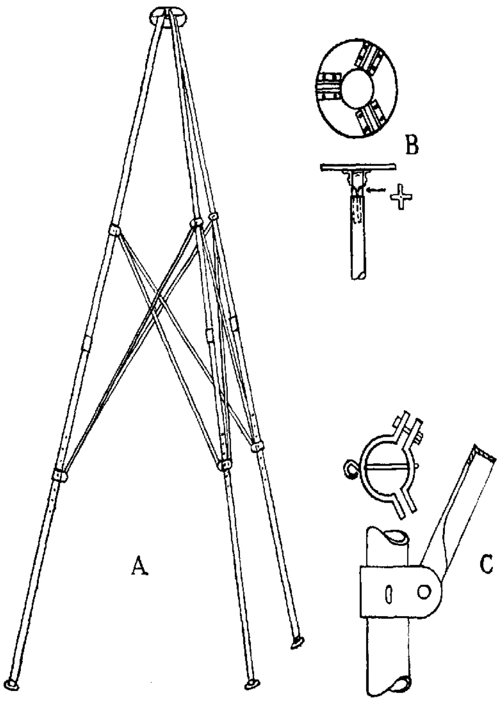
End elevation, showing method of securing platform for carrying load

the casing carrying guides for the bore tube. Great care should be exercised in plumbing the bore tubes for deep borings, the maximum variation being not over one quarter of an inch in the thirty feet depth. The second length of bore tube is now screwed to the first length and on to this the wood clamp Fig. 9, is secured about five feet above ground level. The wood platforms for carrying the load should be bolted on to the clamp and loaded with sandbags or preferably rail cuttings. It is a convenience if a timber platform is placed on the ground having a hole cut in it through which the bore tube sinks, this in addition to acting as a guide for the bore tube, affords a sound footing for the workmen and a bearing for screw or hydraulic jacks, etc.

Tripod or derrick.

The tripod should now be erected over the boring tube in such a position that a rope hanging from the single sheave pulley is centrally over the bore tube. A simple form of tripod or shear legs, Fig. 10, is made up from 4 inches diameter wrought iron pipes and the length of legs should be about 25 feet. Flange feet are more convenient than spiked feet as the latter are liable to sink in soft ground, while the former can be bedded firmly on any sort of ground. The cross struts may be made from 1½ inch by 1½ inch L iron and the lower collars to which these struts are bolted are free to slide up and down the tube, being fixed in position by passing a ½ inch steel pin through the collar and into one of the six holes drilled in the pipe for the purpose. This arrangement, besides allowing of the tripod being easily plumbed over the bore tube, allows of it being closed up umbrella-wise for transport. The join at the apex of the tripod is made from a circular piece of ¾ inch iron plate fifteen inches in diameter, from the centre of which a circular hole of five inches diameter is cut, the legs are hinged to this ring as shewn in the drawing

(B. Fig. 10). The filling piece at the upper end of each leg, which joins the half hinge, might be made from a casting entirely fitting the pipe, but the construction shewn from a piece of cruciform steel has been found more convenient and lighter for transport. The single sheave pulley is suspended from the apex of tripod by hanging the pulley on a short length of 1 inch bar and resting the bar on the ring plate.



(A) Derrick complete. (B) Details of top joint.
(C) Details of sliding collar.
(*Note.*—Illustration shows only one bolt in collar.)

Fig. 10.

A good hemp rope of two and a half to three inches circumference and about 100 feet longer than the proposed total depth of the bore hole is required, one end of this should be passed over the single sheave pulley and spliced round the swivel end of a boring rod. Fig. 11 shows a fairly complete set of boring tools, and it is most improbable that all of these will be required; for borings up to three hundred feet deep, tools of the $6\frac{1}{2}$ inch or 8 inch size will be sufficient unless a considerable depth of rock is to be bored, in which case one or two chisels of the size of the bore tube should be obtained. A complete set of boring rods sufficient to reach to the bottom of the bore hole should also be obtained, these are made up in ten feet lengths, and a suitable section is the square rod of $1\frac{1}{2}$ inches side; although the boring is being made with a rope these rods are a necessity if the rope should break; leaving the boring tool and a length of rope in the bore hole.

Boring tools.

It now depends on the nature of the soil which tool is required for boring; if the soil is sand or clay, then the sludging tool or sand pump should be attached to the swivel head and lowered to the bottom of the bore tube; by raising this tool a few feet and allowing it to drop, the sand or clay is driven into the tool and prevented from dropping out by the flap valve. This operation performed several times should suffice to fill the sludging tool; it should then be withdrawn, emptied, and the operation repeated. If on withdrawal of the sludger little or no material is found in it, the reason may be that the soil is too stiff for the material to get past the valve on each stroke, by pouring water into the bore hole from time to time this difficulty may be overcome, or, in addition, a ten feet length of boring rod

Use of boring tools.

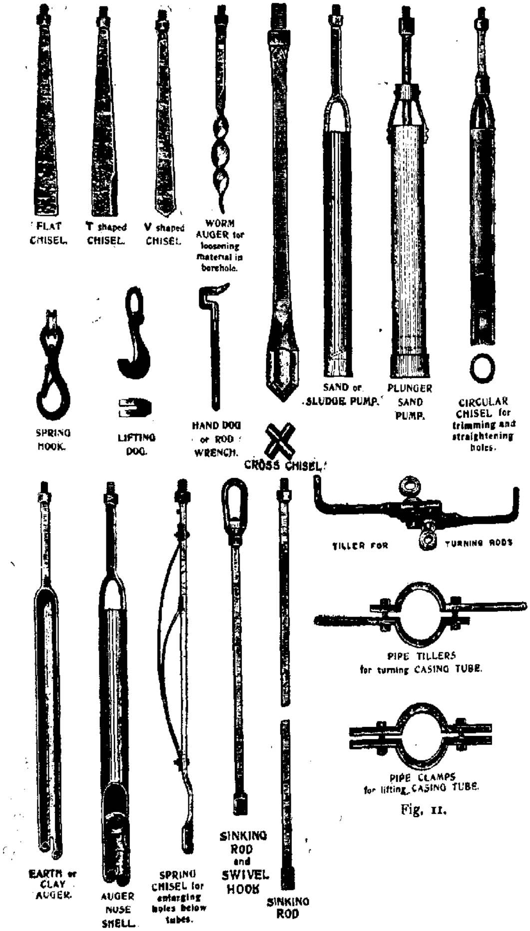

FLAT CHISEL.
T shaped CHISEL.
V shaped CHISEL.
WORM AUGER for loosening material in borehole.
SPRING HOOK.
LIFTING DOG.
HAND DOG or ROD WRENCH.
CROSS CHISEL.
SAND or SLUDGE PUMP.
PLUNGER SAND PUMP.
CIRCULAR CHISEL for trimming and straightening holes.
TILLER FOR TURNING RODS
PIPE TILLERS for turning CASING TUBE.
PIPE CLAMPS for lifting CASING TUBE.
EARTH or CLAY AUGER.
AUGER NOSE SHELL.
SPRING CHISEL for enlarging holes below tubes.
SINKING ROD and SWIVEL HOOK
SINKING ROD

Fig. 11.

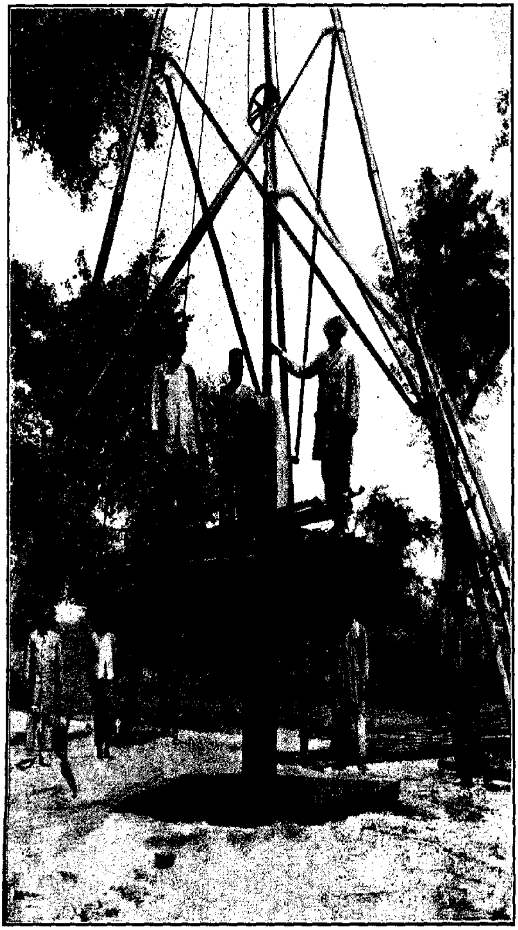
may be interposed between the sludging tool and the swivel head, this additional weight will carry the sludging tool into moderately stiff clay. As the boring operation continues the bore tube is pressed down by the load on it, until the wood clamp carrying the load rests on the heads of two hydraulic or screw jacks, placed on the timber platform on the ground. The bolts of the wood clamp are then loosened and the clamp with its load " jacked up " three or four feet and again securely clamped to the bore tube. Care should be taken that the load on the wood clamp is well balanced, or on loosening the clamp bolts the clamp may tilt slightly and upset part of the load, may be causing serious injury to workmen. The clamp may be unloaded after every five feet of sinking and raised by hand and again loaded, but this operation is extremely slow, particularly after the boring has reached a depth of 100 or 150 feet and the load may be as much as ten tons, with proper care the load can be " jacked up " from time to time throughout the entire boring, only additional load being added as found necessary to carry the bore tube down.

If clay or rock is met with which cannot be bored with the sludging tool, then the sludging tool should be changed for a straight or cross chisel; this tool is used in an exactly similar manner to the sludging tool and its function is to break up the hard subsoil; when a sufficient depth has been broken the sludging tool is again employed to pick up the broken material. In boring through hard material the enlarging tool should be frequently used. This tool bores out the hole a trifle larger than the bore tube, the spring loop on one side of the tool shank presses on one side of the bore tube, while the tool point works under the cutting shoe, at the opposite side. This tool and also the chisels should be given a turn of 20 to 30 degrees every stroke to prevent them from becoming wedged in their own cut. It frequently happens in

boring that the bore tube comes "square" or partly on to a boulder; if the boulder is large it can be bored like ordinary rock, but if small it has to be broken up carefully, and for this purpose the cross chisel will be found most useful. The sludging tool, straight chisel, tee chisel, and cross chisel, will generally be found sufficient for most borings; the writer has never used the so-called enlarging tool, but by "upsetting" the shank of an ordinary tee chisel in such a way that the tool is turned off the centre line of the boring rod, all hard material can be bored easily from under the cutting shoe.

ROD BORING.

The sinking of bore holes with rods extending from ground surface to the tool is carried out in exactly the same manner as the rope system. The rods can be obtained made of ash wood, with the metal male and female screws spliced on, but generally steel rods as described above are employed. The objection to this system of boring is the waste of time in withdrawing and lowering the tools, as the tool can only be raised ten feet at a time, one length of rod unscrewed, then the tool raised the second ten feet and the second length of rod unscrewed, and so on; similarly the lowering of the tool is a very tedious process. When the bore hole has reached a depth of 150 feet, the weight of the rods becomes greater than can be comfortably worked by a gang of men pulling and releasing on the rope attached to the swivel head and which passes over the single sheave pulley as in rope boring. The rods for medium depths of bores are most conveniently worked by a walking beam erected at ground surface; the beam is arranged as a lever, a load is applied at one end to almost balance the weight of the rods and reciprocating motion is imparted to the tool by the workmen stepping on and off the loaded end of the beam, or in deep



Sinking 12-inch boring tube by water jet system, sub-soil is broken up and washed out by the water overflowing at mouth of bore tube.

borings the walking beam is operated by a crank connected to a steam or other engine. In order to obviate the jarring effect of the great length of rods, particularly in very deep borings when steam or other power is used to operate the rods, a trip link is introduced twenty or thirty feet above the tool; this consists of a telescopic rod arranged with a very ingenious system of clutches which allows of the tool and the length of rod below the trip link, dropping independently of the length of rod above the trip link, this arrangement also prevents the tool becoming wedged in hard subsoil or rock on account of being overdriven and also minimises the chances of broken rods due to fatigue and consequent crystallization of structure owing to constant vibration.

WATER JET BORING.

In water jet boring the tripod and the starting of the bore tube is the same as for the methods already described. From the pulley of the tripod a length of $3\frac{1}{2}$ inches diameter ordinary W. I. pipe is suspended within the bore tube, this tube is fitted with a nozzle at its lower end, gradually tapering to an orifice of $1\frac{1}{4}$ inches diameter, the nozzle is kept about six inches above the bottom of the bore hole and a suitable connection with a steam or other power pump having been made at the upper end of the pipe, water is pumped into the bore hole. The effect of the water jet impinging on the bottom of the bore hole is to loosen and break up the subsoil which is washed out of the bore tube by the upward current of water; as the subsoil is washed out, the bore tube sinks and the $3\frac{1}{2}$ inch jet pipe is lowered to maintain a distance of a few inches only between the nozzle and the bottom of the boring.

This system of boring is extremely expeditious in sand, clay or other soft subsoils, and even in soft or

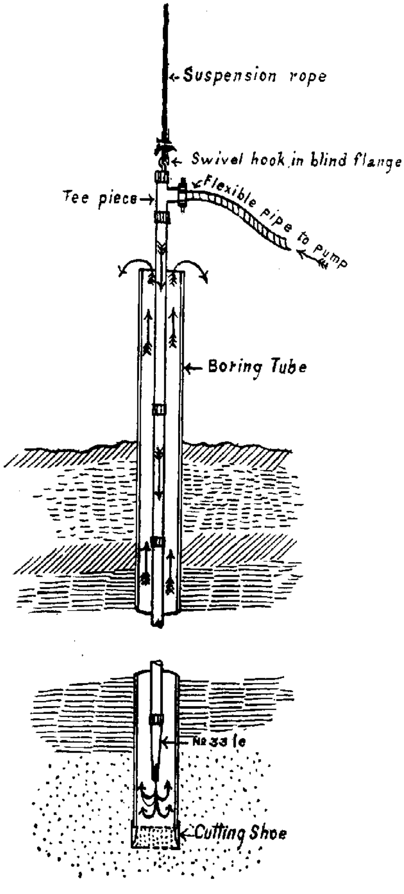


Fig. 12. {Diagram of water jet system of boring.
Arrows show direction of flow of water.

rotten rock or kankar, it is quite satisfactory if a steel spike is secured to the nozzle and the jet pipe used as a jumper to break up these materials which are then washed out by the jet. For borings which are mostly in rock, hollow chisels of various cross sections can be obtained, this form of tool allows of its use in combination with the water jet. The writer has sunk a large number of borings in Northern India by this system of water jet and with twelve inch boring tubes in sand, sandy clay and clay with a stratum of two to three feet of kankar, the average rate of progress is fifteen feet per day or practically double the rate of progress with the ordinary sand pump or sludging tool. The power of pump should not be less than 150 gallons per minute, and an extremely suitable make for this work is the portable steam fire engine of this capacity, built by Messrs. Merryweather & Co. The pump is connected to the upper end of the jet pipe by a fire hose, a tee piece being fitted to the upper end of the jet pipe and the hose coupled to the tee; the upper end of the tee is provided with a screwed plug fitted with a swivel hook for suspending from the block of tripod; frontispiece and Fig. 12 show all the details of this system of boring.

BORING WITH MARTIN'S SLUDGER.

This system is practically the reverse of the water jet system of boring. A cross or S chisel is attached to the lower end of the jet pipe, in place of the nozzle, and the sludger is screwed to the upper end of the pipe and secured to the rope passing over the pulley of the tripod. A reciprocating motion is given to the boring tools and a liberal supply of water poured frequently into the bore tube. The sand or other material forming the subsoil is pumped out along with the water through the pipe and sludger. The advantage of this, like the water jet system, is that the boring process is continuous

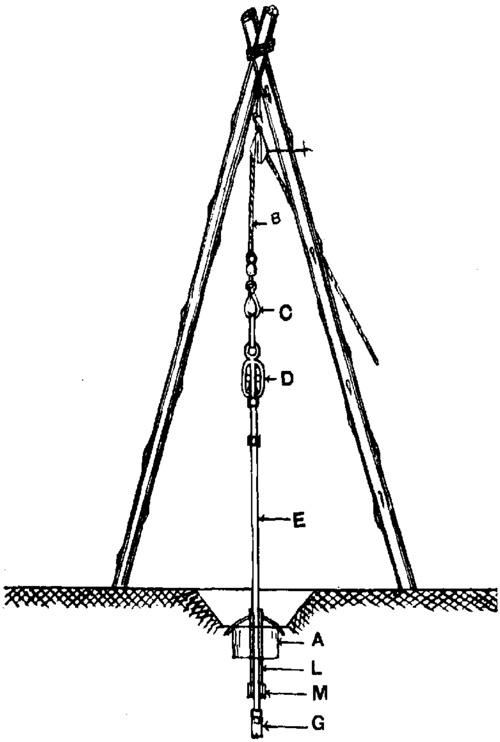


Fig. 13.—(B) Sinking rope. (C) Swivel hook. (D) Martin's sludger. (E) Boring rod which is hollow in this case. (A) Guide drum. (L) Casing or boring tube. (M) Cutting shoe. (G) Boring tool.

and the tool does not require to be withdrawn until the full depth of boring is reached. The length of stroke of the boring tool should be about three feet, and downward stroke must be smart. The water supply to the bore or casing tube should be plentiful and the closer the sludging tool is to the water level the better will be the results as the sludger works best with a medium suction lift. Fig. 13 shows the general arrangement for this system of boring.

CORE BORING.

This system is most generally used for deep borings in rock and prospecting work where accurate samples of the rocks traversed are required. As its name implies, this system preserves the core intact and an absolutely accurate geological section showing the exact depth and inclination of each stratum can be prepared.

The working part of the drill consists of the so-called crown, which is a short piece of cast steel tube, into one end of this tube a number of black diamonds are fastened. The upper end of this cast steel tube or crown is secured to steel pipes which take the place of boring rods. Machinery at ground surface cause the pipes and crown to rotate, the diamond studded edge of the latter making an annular cut in the solid rock leaving a core, which breaking off from time to time is caught by an internal shoulder in the crown and brought to the surface when the tool is raised at intervals. The detritus is washed out by a constant stream of water being pumped down the hollow rod or pipe and returning to ground surface between the outside of the steel pipe and the bore hole.

With this system boring can be carried on continuously at a speed quite unattainable by any of the methods above described. A recent improvement in the diamond drill is the fixing of diamonds in the crown. At one time

diamonds were set direct into the crown and an expert diamond setter was required at the site of the boring operation; now each diamond is secured in a small steel plate and when a diamond is lost or requires resetting, etc., the plate is unscrewed from the crown and a fresh plate and diamond substituted. The Calyx system of boring is in general principle the same as above, but in place of a diamond studded crown, a crown fitted with steel balls or cutters is used.

Core boring can be carried out expeditiously and without trouble to depths frequently over three thousand feet.

BORING IN WELLS.

When a convoluted tube well is to be used for augmenting the supply of an existing well or in a new well which may be necessary as a sump for placing a pump within suction range of the water surface, the procedure is as follows :—The well should be covered over with a timber platform in which a hole is cut large enough for the boring tube to slip through; several lengths of boring tube are screwed together and passed through the hole in the platform until the lower end of the boring tube fitted with its cutting shoe, rests on the bottom or floor of the well, the upper end of the boring tube projecting several feet above the platform. The wood clamp for carrying the load is secured to the boring tube a few feet above the platform, the load applied, and boring by any of the described methods is then commenced.

COMMON ACCIDENTS IN BORING.

Broken cables.

In boring by the rope system one of the most frequent accidents is breakage of the cable; when this happens a new string of tools has to be prepared consisting of the swivel

hook or rope socket, a length of iron boring rod to act as a weight or sinking bar, a trip link which allows of the tool being jerked or jarred upwards and a rope "spear" or "grab." The latter is simply a two or three-pronged instrument about four feet in length, between the prongs of which there are several upturned spikes. On this string of tools being allowed to fall heavily on the coil of cable it seldom fails to secure a firm grip, but if the tools have become imbedded in the débris at the bottom of the bore hole, the trip link will come into operation allowing the grab to be jerked upwards, thus tearing off fragments of the broken rope until the head of the lost tool or tools is felt.

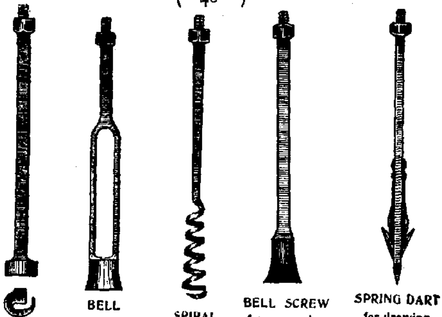
Lost tools.

When a tool is lost through breakage of the cable at the tool or when the cable has been jerked off as above, then the tool is recovered by feeling with a worm screw or cleat, the worm of the former engaging in the swivel hook of the tool, or the L-shaped portion of the cleat can be hooked round the neck, under the swelled head of the rope socket.

Unscrewed and broken rods.

Rods becoming unscrewed can be recovered by lowering a bell box over the head of the unscrewed rod. The bell box consists of a short length of tapered tube, the wide mouth of which is an easy fit in the bore tube, the upper end being provided with a semi-circular flap valve. On lowering this tool over the rod, the valve is pressed up and on withdrawing the tool, the valve presses down and jambs under the neck of the rod.

In the case of broken rods the bell box is replaced by a bell screw which is similar in shape to the bell box, only the flap valve is replaced by a hard steel die; this tool is lowered by rods or tubes from the surface and on these being turned a screw is cut on the broken rod end and the lost tools recovered.



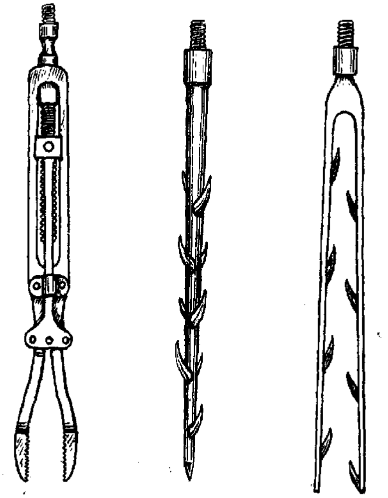
CROW'S FOOT. or cleat

BELL BOX.

SPIRAL WORM.

BELL SCREW for recovering broken rods.

SPRING DART for drawing out CASING TUBE.



screw grab or tongs

Rope spears.

Fig. 14.

Considerable trouble can be caused by a boring tool breaking when firmly stuck in a hard soil or rock, as there is no head or neck which can be gripped or screwed and sometimes, if the broken portion is not already stuck in the soil, it may become wedged owing to the searching operation, or it may be inclined at an angle under the cutting shoe of the bore tube.

Broken tools.

The position of the broken piece can be found by lowering an impression block: this consists of two forms according to requirements, either a circular disc of wood attached centrally to the boring rods, the lower surface of which is studded with nails projecting half an inch from the wood surface and plastered over with clay puddle, or it may consist of a long cylindrical or slightly tapering piece of wood, the surface of which is similarly coated with plastic clay or other substance. The position of the broken piece having been found, it may be forced into a more suitable position for removal by twisting the cleat hook behind it; if firmly wedged the piece may be loosened by boring around it with smaller sized tools or by the water jet. When loosened the tool may be picked up by the grab tongs, one form of which is shewn on Fig. 14. Sometimes it is necessary to lower a drill at the end of the boring rod and drill and tap the broken piece, the drill and tap being kept in the correct position by spring guides attached to the boring rod and pressing on the boring tube. If the position of the broken tool is favourable and the subsoil hard, it may be pulverised and driven to one side clear of the bore tube with a steel bit at the end of heavy sinking rods. For extreme cases, in deep borings where it is less expensive to remove a broken and firmly fixed tool than to abandon the boring, the tool may be cemented in with portland cement, and when set hard the whole

plug and the tool may be drilled through with a calyx or diamond drill.

DEPTH OF BORING.

FOR tube wells which are to be sunk from ground surface the minimum depth of boring should be equal to the length of the convoluted tube well, plus ten feet, plus the depth from ground surface to dry weather spring level. When the convoluted tube is to be sunk in an existing well, the top of the convoluted tube should generally be not less than ten feet below the bottom or floor of the well. These depths assume that a good water bearing stratum of at least the required depth exists; it may frequently be found that by continuing the boring to a greater depth a much coarser and more highly porous sand exists. In such cases it is advisable to sink the convoluted tube deeper and thereby obtain the required discharge under a less head than would otherwise be the case. Again, the water bearing stratum may not be continuous but may be intersected by strata of clay or other impervious material; for example, in the writer's experience of one district a good water bearing sand stratum was intersected at a depth of 30 feet below spring level by a stratum of clay ten feet thick. It was desired to sink a five-inch convoluted tube well for a discharge of 15,000 gallons per hour. The length of this size of tube well is fifty-four feet. The boring was continued to a depth of 74 feet below spring level and 34 feet of convoluted tube well inserted, then a ten-feet ength of plain pipe and then the remaining 20 feet of convoluted tube; thus the clay stratum was passed by a plain pipe. There is sometimes only a limited depth of water bearing stratum and in such cases the full length of convoluted tube cannot be made use of; in one instance the writer was asked to provide a supply of 40,000 gallons per hour and the intention was to sink

two standard seven-inch tubes, each 74 feet long. On boring operations being commenced it was discovered that the water bearing stratum only extended to a depth of 50 feet below spring level, so the seven-inch convoluted tube wells were halved and the four halves used as separate tube wells; but instead of attaching a 7-inch plain tube to the upper end of the convoluted tube, a reducing socket was fixed and a 5-inch plain pipe attached, the object of this reduction being to ensure all sand which came into the tube well during the first few days of working, being held in suspension and thereby carried out of the tube: in other words, the 5-inch pipe provided a higher velocity than would have been the case with the seven-inch pipe.

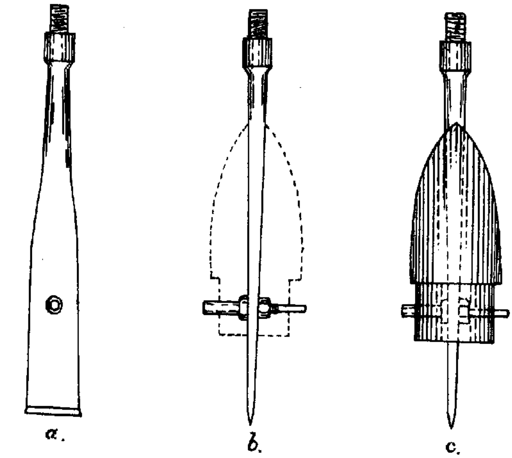
SINKING CONVOLUTED TUBE WELLS.

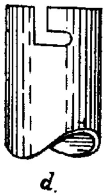
HAVING settled on the size of tube well required and the boring completed, the next operation is to sink the tube well. Convoluted tube wells are sent out in lengths of from seven to ten feet according to the diameter, and it will be observed that one length is provided at one end with a cap or blind end, this is the first length to be inserted in the bore. One of the iron clips supplied with the tube wells is clamped to the upper end of this first length, *i.e.*, the end which is open, and the clamp should be fitted just under the socket so that the socket acts as a shoulder and prevents the tube slipping through the clamp, should the latter not have been securely screwed up. The rope passing over the pulley of the tripod is provided with a swivel hook and to this hook a short double chain sling should be suspended; the hooks of the chain sling are slipped under the projecting lugs of the clip and the length of tube well raised and suspended over the bore tube and then gently lowered in the bore tube until the lugs of the clip rest on the mouth of the bore tube. A second clip is now fixed

under the socket of the second length of tube and this length raised and its lower or spigot end slipped into the socket of the first length ; a mark will be found on the socket of the first length and a corresponding mark on the spigot of the second length must be brought opposite this mark, the stud holes of the socket and spigot will then correspond and when the studs are screwed in, the axes of the two lengths will be in one straight line. The clamp is now removed from under the socket of the first length and the two lengths lowered until the lugs of the clamp fixed under the socket of the second length rest on the mouth of the bore tube; the operation is repeated until all the lengths have been coupled up and the clip lugs of the last length of convoluted tube are resting on the mouth of the bore tube; the first length of plain pipe is now coupled to the upper end of the convoluted tube by a similar type of stud joint as employed in the convoluted tube, the remaining lengths of plain pipe may be jointed by the ordinary screwed socket joints with which the plain pipes are usually provided. If pumping is to be done from ground surface, this plain pipe will be continued up to ground surface and temporarily closed with a wood plug; but if the tube well is to be used to augment the supply in an existing well, or if a sump is to be used for pumping purposes, then the upper end of the plain pipe will be, say, 12 feet below dry weather spring level. In this latter case the method of lowering the tube well is as follows :—

The convoluted tube and the plain pipe attached is lowered as above and the clip secured under the socket of the last plain pipe supports the whole tube well on the mouth of the bore tube. Two L-shaped slots are cut in the socket of this plain pipe and into these slots a lifting tool is fixed. The lifting tool (see Fig. 15)

DETAILS OF LIFTING TOOL.





(*a*) Boring chisel from which lifting tool is made.
(*b*) Side elevation of chisel showing lifting bar fixed.
(*c*) Showing wood shield built round tool.
(*d*) Upper end of plain pipe with slots cut.

Fig. 15.

consists of a short length of flat bar iron, one end of which is screwed to fit the ordinary boring rods, a hole is drilled in the bar and fitted with a piece of round bar iron provided with a shoulder and lock nut to secure it centrally on the flat bar, the ends of this round bar are slipped into the vertical portion of the L slots on the socket, the bar is given a part turn to the left, thus engaging the horizontal position of the L slots. In order to provide a temporary plug for the tube well, this tool should be built round with wood as shewn in B. & C. Fig. 15. The tube well is now lowered in exactly the same manner as when the plain pipe comes to ground surface, only lengths of boring rod are used in place of the plain pipe and the tube lowered until it rests on the bottom of the bore hole. The tube well is now ready for shrouding.

Shrouding the tube well.

The material used for shrouding the tube well is a good coarse clean sand, carefully screened to the size which will pass through a screen having 10 meshes to the lineal inch and will be retained on a screen having forty meshes to the lineal inch. The quantity of this sand which is required to fill one foot of the annular space between the convoluted tube and the bore tube, should be carefully calculated and the calculation verified by an actual test on a short length of boring pipe with a piece of convoluted tube, or other tube of exactly the same dimensions, placed inside the bore tube. A tin measure of one-eighth cubic foot capacity is a convenient size to use for filling in this sand : the measure should be filled each time and sufficient sand poured into the space between the convoluted tube and the bore tube to fill a depth of two feet, the bore tube should then be withdrawn one foot only, and again sand poured in to fill a depth of one foot only, the bore tube withdrawn one foot and a further depth of one foot of sand poured

in, and so on, for the entire length of the convoluted tube. By this method of filling the sand is always one foot higher than the bottom of the bore tube, thus ensuring a continuous jacket or shroud of the coarse sand round the tube well. If the sand is filled in for a greater depth than one foot at a time without drawing the bore tube, the sand is liable to bind on the convoluted tube when drawing the bore tube and the straining material may be damaged, or if a considerable depth of sand is filled, then the convoluted tube may be sand-bound to such an extent that it will be raised with the bore tube; it is, therefore, expedient to keep the sand never more than two feet or less than one foot in advance of the bottom of the bore tube. Although shrouding is not absolutely necessary in subsoils of which the particles are larger than will pass through a screen of sixty to eighty meshes to the lineal inch, still it forms a considerable protection against packing on the outside of the straining material and as it ensures a high porosity subsoil in contact with the straining material from the start it is quite worth the little trouble and cost involved.

Drawing the bore tube.

The bore tube is withdrawn while the shrouding described above is being applied, the method of withdrawal being as follows:—The wood clamp which is used for carrying the load in sinking (see Fig. 9) is secured to the boring tube a short distance above the timber platform fixed at ground level; two screws or hydraulic jacks are placed on the platform, one on each side of and close to the bore tube, the upper lifting plates of the jack bearing on the under side of the wood clamp, as the jacks are screwed or pumped up the bore tube is withdrawn, the wood clamp being moved down from time to time to suit the range of the lifting jacks. When the bore tube has been raised so that the first joint is from two to three feet above the timber platform,

the clamp should be moved down to the timber platform and held with a crowbar to prevent the bore tube from turning when the upper length is being unscrewed. To unscrew the upper length of bore tube a long crowbar placed against and at right angles to the bore tube is wrapped twice round with a length of light chain which is then wrapped several times round the bore tube; this crowbar acts as a powerful lever operated by several workmen holding the lever and marching round the bore tube in an anti-clockwise direction; the first movement of the crowbar serves to tighten the chain on the bore tube, friction then being sufficient to hold the lever as part of the bore tube which is unscrewed as the lever is turned round. An iron clamp should be secured to the upper end of the length of bore tube which is to be unscrewed and this clamp hooked to the chain sling hanging from the swivel hook of the lifting tackle on the tripod, the lifting tackle taking the weight of the length of bore tube as soon as it is unscrewed.

Bore tubes of twelve and fifteen inches diameter can be easily withdrawn by the above method from borings up to two hundred feet in depth, at the rate of seventy feet per working day.

Having completed the withdrawal of the bore tube, the tube well is now ready for use, unless the tube is sunk in a well in which the water level is to be reduced below that level which would exceed the critical velocity of the subsoil forming the well floor; or if the tube well is sunk in a small chamber or well to be used as a pump sump. In such cases the floors of the wells or chambers should be sealed with cement concrete. A good substantial seal should be put in, say, from two to three feet in thickness, and the writer has proved that a four to one cement concrete is most suitable for this purpose. The concrete is composed of one part best portland cement, two and three-quarter parts stone broken to pass through

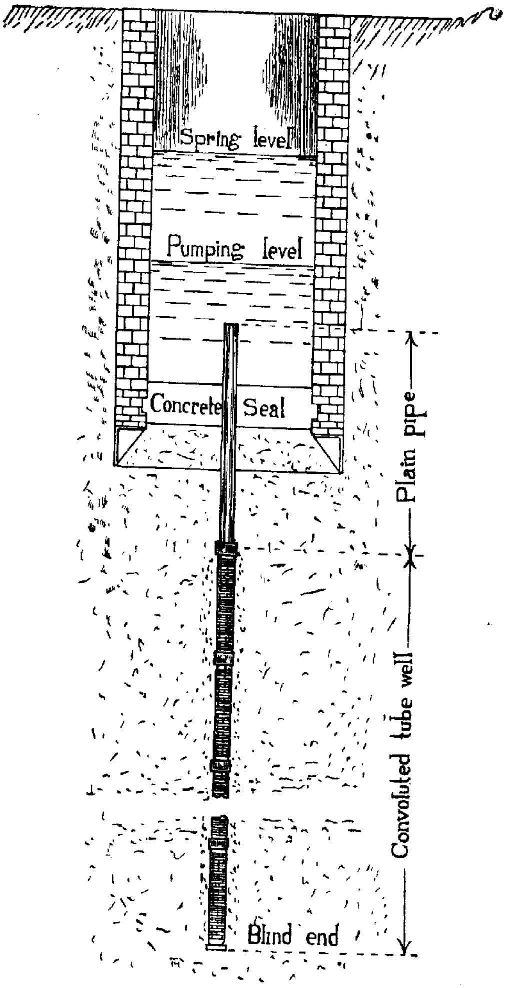


Fig. 16.—Tube well sunk in existing well (concrete seal may be omitted if critical velocity of well is not to be exceeded).

a one and a half inch ring and one and a quarter parts clean *sharp* river or pit sand, all by measure; if one cubic foot is taken as the unit of measurement, then the total of five cubic feet according to the above proportions will be found quite sufficient to mix at one batch. The ingredients should be thoroughly mixed in the dry state and again mixed with the addition of just sufficient water to damp all particles; the mixture is now ready for loading into the well or pump sump, and this is conveniently done from an ordinary galvanised iron bucket. A few holes are made in the bottom of the bucket and a rope secured to one of the holes, the other end of the rope is secured to the handle; concrete is put in the bucket and lowered by the rope attached to the handle until the bucket rests on the floor of the well, then the rope attached to the bottom of the bucket is used to raise the bucket, thus upsetting and emptying the bucket at the bottom of the well, the additional holes in the bottom of the bucket allowing water to pass in and expedite the emptying of the bucket; this method prevents the cement from being washed out from the other ingredients and gives a substantial water-tight floor; when the well is being specially sunk as a sump for a tube well, the masonry walls for a foot or two above the curb should be built corbelled out and in, to act as a bond for the reception of the concrete and obviate the straight joint between the masonry and concrete.

PUMPING FROM TUBE WELLS.

Bullock wheels.

WITH the smallest size of convoluted tube well capable of yielding one quarter cusec, or over 5,000 gallons per hour, the ordinary Persian wheel is most often employed; the reason being that this size of tube well is frequently used for increasing the water supply of existing wells for irrigation purposes, in which a Persian wheel is already working. Few of the old wood Persian wheels lift

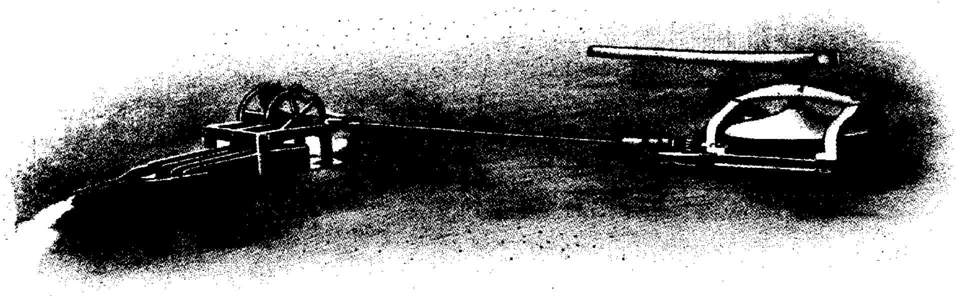


Fig. 17.—Cawnpore Bullock power patent chain pumps.

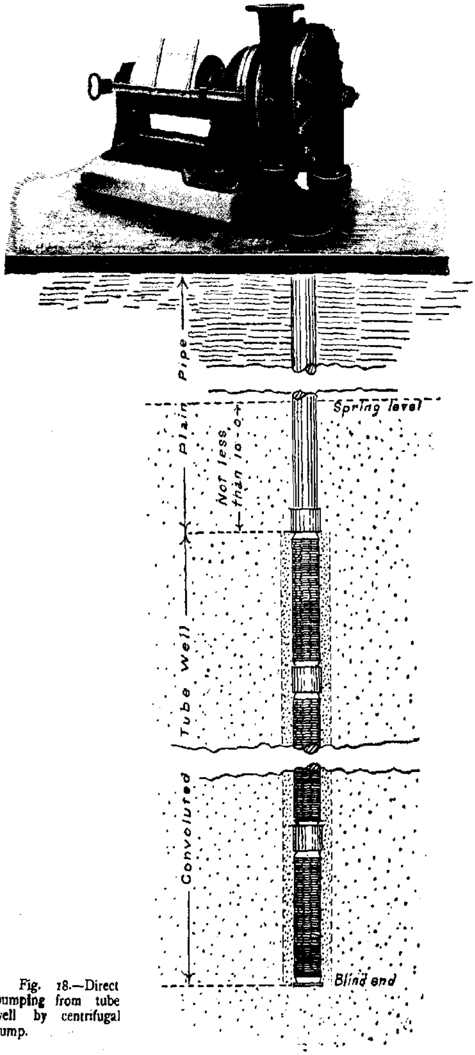


Fig. 18.—Direct pumping from tube well by centrifugal pump.

more than 2,000 gallons per hour and the wheels are frequently duplicated when a small tube well has been installed, or bullock power metal Persian wheels or chain pumps substituted for the wood Persian wheels. When the old-fashioned wood wheels are used it is advisable to fix a globe-shaped wire cage over the mouth of the tube well to prevent broken earthenware vessels dropping from the Persian wheel into the tube. Fig. 17 shows a general arrangement of metal gearing for bullock power and chain pump in use in tube well augmented wells.

Power pumps.

For irrigation purposes or public water supply from the larger sizes of convoluted tube wells, power pumps will be required and local conditions must decide the type of pump and whether it is to be driven by steam, electricty or oil, etc.

When water level is within ten or twelve feet of ground surface, then the pump may be placed on ground surface and either connected direct to the tube well or the tube well may be sunk in a small pump sump of three or four feet diameter and the suction pipe from the pump carried down into the sump. Fig. 18 illustrates direct pumping from tube.

Pumping by the air lift system.

Compressed air as a means of lifting water from tube wells is in favourable circumstances a simple method of operating either a battery of several tube wells from one compressor plant, or it may with equal economy be employed to pump from only one tube well. For a large water supply requiring several tube wells, the most economical arrangement is to sink the tube wells equidistant on the circumference of a circle at the centre of which the compressors are situated; the water delivery pipes from each tube well radiating to collection or storage tanks situated over the compressors. This system allows an exceptionally large scope for

extension, as additional wells can be added as required on a concentric larger circle.

In order to obtain as high an efficiency by the air lift system as by ordinary pumps, the amount of submergence of the air inlet should be carefully fixed; when the lift is small the submergence may be as much as $2\frac{1}{2}$ times the lift, but on high lifts it is not advisable to have a submergence much more than equal to the lift. For example, where water level is 30 feet below the point of discharge the submergence over the air nozzle should be about 75 feet; when water level is 300 feet below the point of discharge a submergence of 300 feet would be ample. In dealing with high lifts and consequently high air pressures, there is considerable falling off in efficiency if the submergence is too great.

The quantity of air required to pump any given quantity of water depends not only on the submergence but also on the height to which the water is to be lifted. When the lift is 100 feet and the air inlet submerged 200 feet, then 0·62 cubic feet of free air is required per gallon of water. If the air inlet is submerged 200 feet and the lift increased to 200 feet, then 1·25 cubic feet of air is required to lift each gallon of water.

The air pressure required depends on the amount of submergence and lift. With a lift of 200 feet and submergence of 200 feet the working pressure would be between 85 and 90 lbs. per square inch representing the water weight over the nozzle of air inlet. This working pressure has to be considerably exceeded in order to start pumping by overcoming friction in the rising main, and inertia of the long column of water.

Tube wells which are to be worked by the air lift system require to be made deeper than when other types of pumps are employed; this is in order to allow the air

inlet the proper amount of submergence, the air inlet nozzle should be placed in the plain pipe and close to, but not within, the convoluted tube pipes. Fig. 20 shows the correct position of the air inlet and general arrangement of the plant when in use with convoluted tube wells. The air pipe may be led down the outside of the rising main or discharge pipe and this arrangement is preferable to carrying the air pipe inside the rising main and thereby increasing friction owing to additional surface and the couplings of the air pipe. In many cases, however, this friction may be neglected and considerable saving effected by using the plain pipe

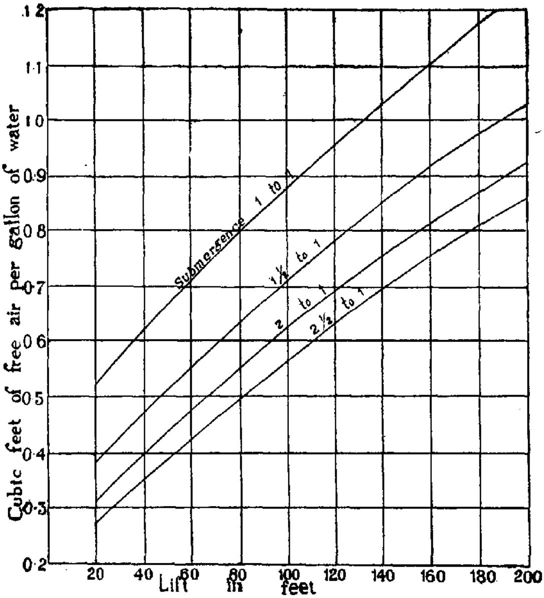


Fig. 19.—Diagram showing quantity of free air required per gallon of water with varying submergence of air nozzle.

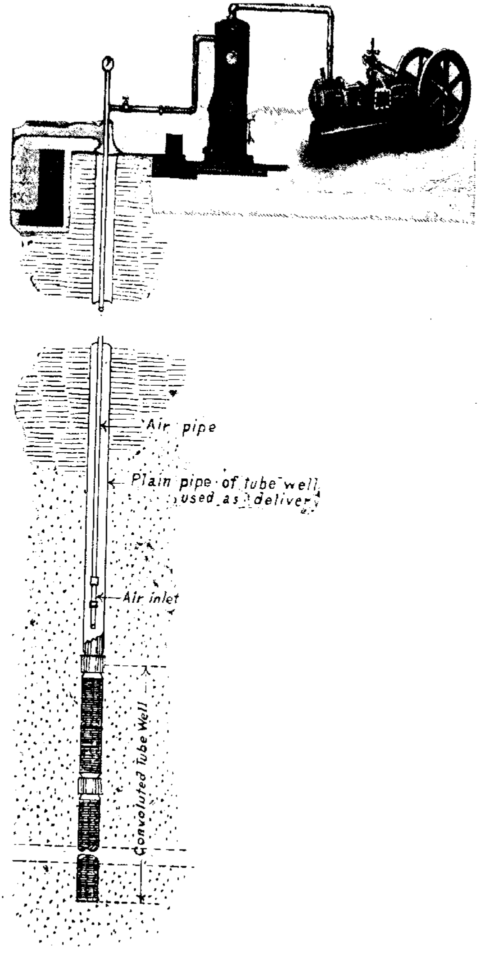


Fig. 20.—General arrangement of Worthington Air Lift system, for raising water from deep tube wells.

Note.—It is sometimes advantageous to keep the air pipe outside the delivery pipe, thus avoiding the obstruction and friction caused by air pipe.

of the tube well as the rising main and inserting the air tube therein as shown on illustration.

The beauty of the air lift system is its simplicity: there are no parts whatever in the tube well which are likely to become worn or give any trouble, no matter what the water depth may be; all the plant is at ground surface and easily accessible.

Various types of pumping plant.

It is impossible to give particulars of all the forms of pumps which may be successfully employed for lifting water from tube wells, as local conditions and requirements must decide the type and power best suited for individual cases. The horizontal reciprocating pump is largely used for public water supplies in India and this form is well suited for all situations where the spring level is fairly near ground level; the power most generally in use for driving these pumps is steam and the pump barrel is arranged in tandem with the steam cylinder; one piston rod carries the piston at one end and pump plunger at the other, thereby allowing of an extremely neat and compact arrangement. A pump of this type may be fixed at ground level and the plain pipe of the tube well connected direct to the suction pipe of the pump, or in cases where water level is beyond the economical suction reach of the pump, the pump may be placed on cross girders in a pump sump close to water level, while the steam boilers are placed at ground level. When a battery of tube wells is required to yield the necessary supply, they may be arranged as in the air lift system with a separate suction pipe radiating to one main suction chamber of the pump, or they may be arranged in a straight line having the pumping plant midway on the line and a main suction pipe lying parallel and close to the tube wells with a branch suction pipe to each well.

Although the pumps may be connected direct to the plain portion of the tube well and a special form of suction or foot valve fitted to each tube well when sinking it, or the valve may be omitted and a starting injection used in its place; the author prefers to sink each tube well in a small diameter pump sump. In cases when spring level is comparatively close to ground level this sump may be of masonry, an internal diameter of three feet being sufficient, the bottom of the sump should be twelve or fifteen feet below spring level according to subsoil and be sealed with a cement concrete plug, the plain pipe of the tube well passing two or three feet through the plug into the sump. This arrangement, although slightly more expensive than with a direct connection to the tube well, allows of a much less expensive form of foot valve being employed and of complete accessibility to the foot valve for repairs, etc. The tube well may be examined or washed out in a few minutes without the necessity of excavation or disconnecting any pipes.

For general water supplies and irrigation purposes where the spring level is comparatively close to ground level and thus allowing of any of the ordinary forms of pumps being employed, the author prefers to use centrifugal pumps in most cases, chiefly on account of their freedom from valves or parts liable to get out of order, general simplicity and small space occupied.

Fig. 21 represents a centrifugal pump direct coupled to a Reavell two-cylinder high speed paraffin engine, this form of pumping plant is extremely compact and strongly built and so free from vibration that it will work well when suspended from a crane or standing on any class of floor without being fixed thereto. A plant of this type, capable of pumping over 30,000 gallons of water per hour can be placed on a platform in a sump of eight or nine feet in diameter and will allow ample

space for the mechanic in charge to attend to it in every way.

In cases where an existing open well has been the only source of water supply of two or three thousand gallons per hour, the supply may be economically increased by sinking a tube well of the required discharge in the well, the floor of which is then sealed and a pumping plant of the above description mounted on a platform built a few feet above spring level. This direct coupled type of pumping plant is slightly more expensive

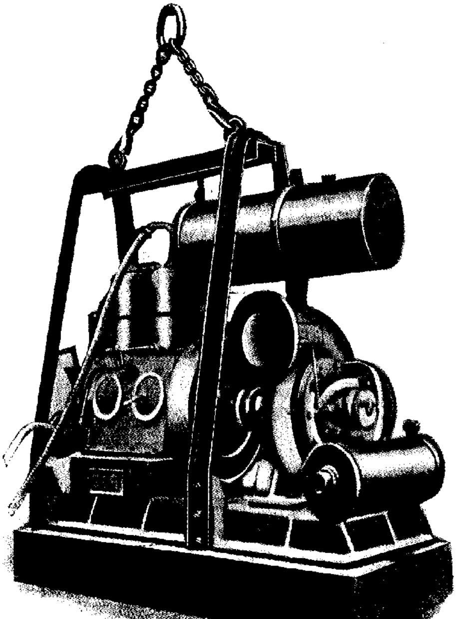


Fig. 21.—Reavell high speed engine direct coupled to centrifugal pump; arranged for slinging on cable.

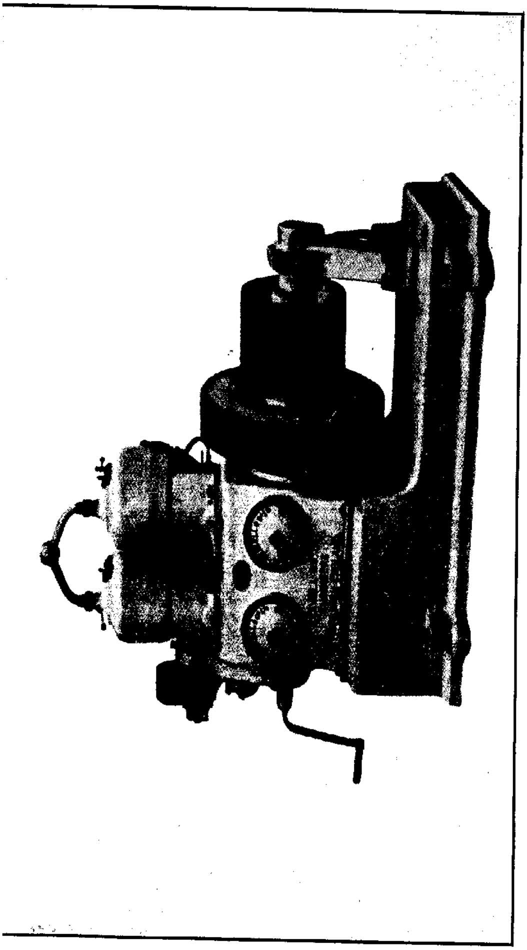


Fig. 22.—Reavell high speed engine arranged for belt drive.

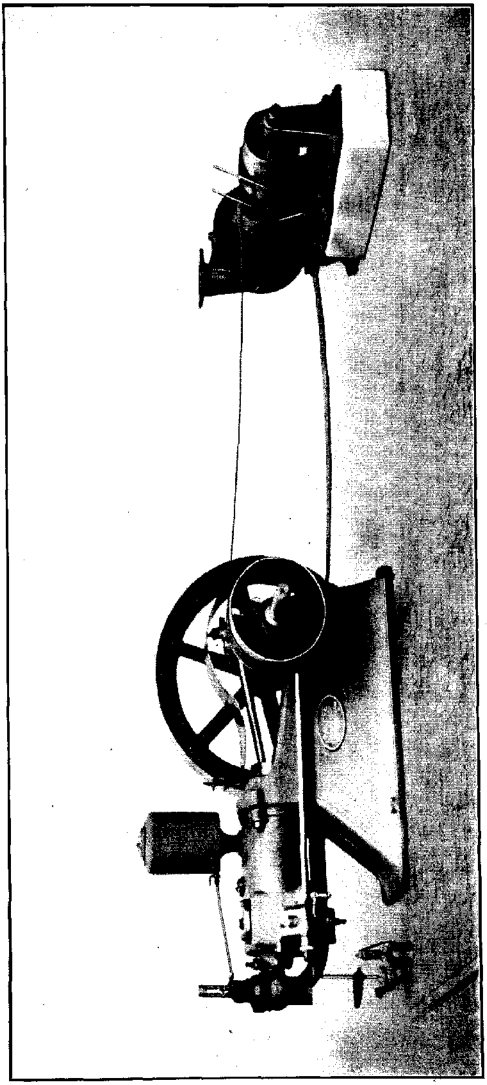


Fig. 23.—Tangyes' horizontal oil engine belt driving "Tangyro" pump.

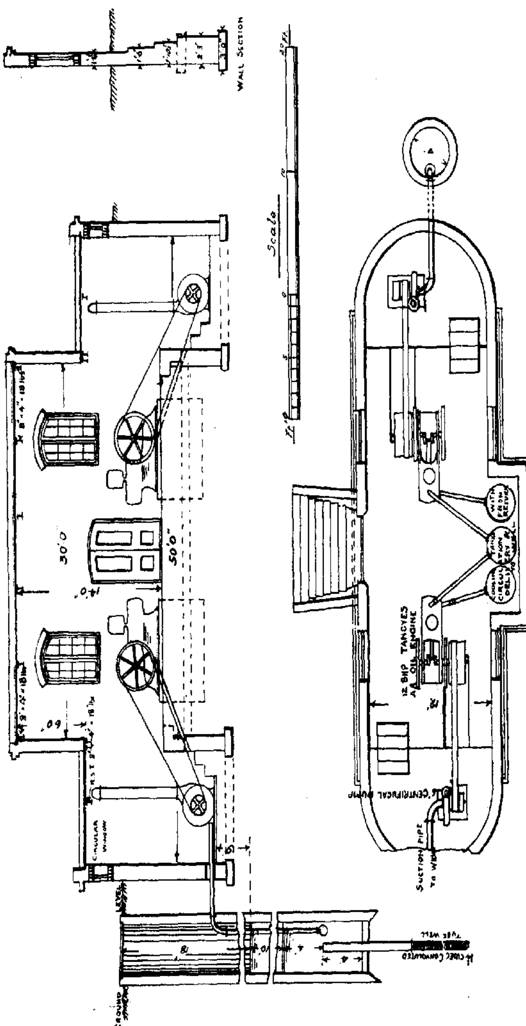


Fig. 24.—Pumping plant and tube wells in duplicate for supply of 28,000 gallons per hour.

than a centrifugal pump belt driven from the ordinary horizontal type of oil engine, but the small space it occupies frequently makes it a much less expensive plant to instal, on account of the absence of large engine houses which may require to be built considerably below ground level, in order to bring the belt driven pump within the economical suction reach of the water. These engines are fitted with Bosch magneto and are generally started on petrol for a few minutes until the required temperature is reached, but can also be arranged to start direct on kerosine oil, the required temperature being obtained by lamp heat applied for a few minutes as in many forms of the ordinary oil engine. The running cost of these engines compares favourably with that of the ordinary oil engine.

Fig. 23 represents a horizontal oil engine belt driving a centrifugal pump. Fig. 24 shows a typical case where the water level is fairly near ground surface, the pump having been stepped down a few feet to bring it close to water level. Fig. 25 shows the horizontal engine driving a horizontal centrifugal pump through a vertical shaft and twisted belt drive. This arrangement being suitable when water level in some considerable depth below ground surface and yet not deep enough to warrant the use of a pump capable of working in the tube well itself.

Another popular form of pump suitable for these latter conditions is the double acting vertical type of pump which is very compact and steady in its working. Fig. 26 shows a pump of this type bolted to a platform in the pump sump and driven by an oil engine at ground surface. Fig. 27 shows a somewhat similar type of pump driven by a vertical steam engine placed over the pump sump.

The power to be employed in driving pumps must be decided almost entirely by the locality in which the

pump is to be worked. In many districts of India where the cost of coal is high on account of the distance from the coalfields and in districts in which there are no proper roads for the carriage of coal, oil engines can be run much more cheaply than steam engines. The author has installed a number of Tangyes' Oil Engines, some of which have been working for several years at

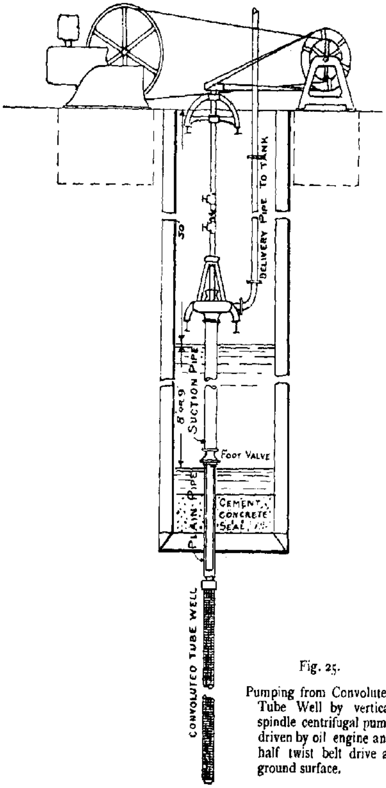


Fig. 25.

Pumping from Convoluted Tube Well by vertical spindle centrifugal pump driven by oil engine and half twist belt drive at ground surface.

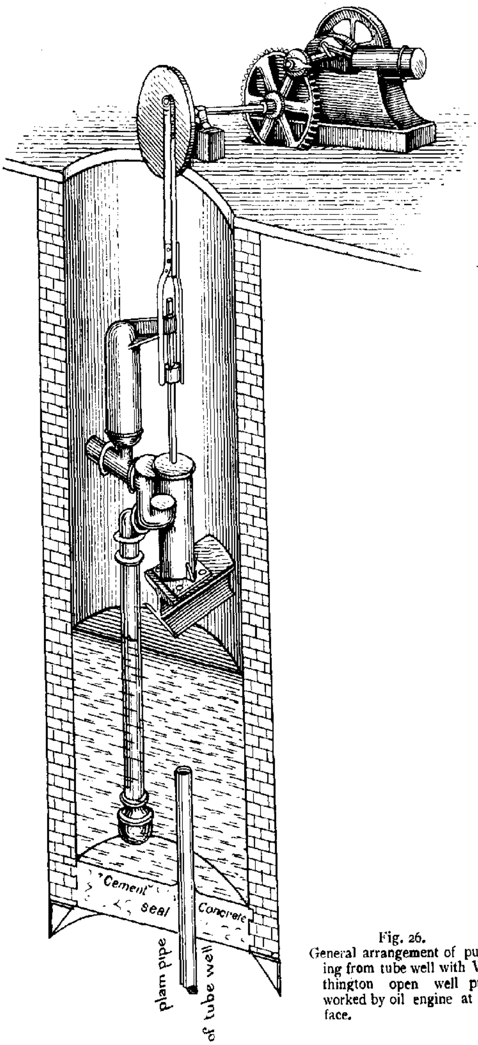


Fig. 26.
General arrangement of pumping from tube well with Worthington open well pump worked by oil engine at surface.

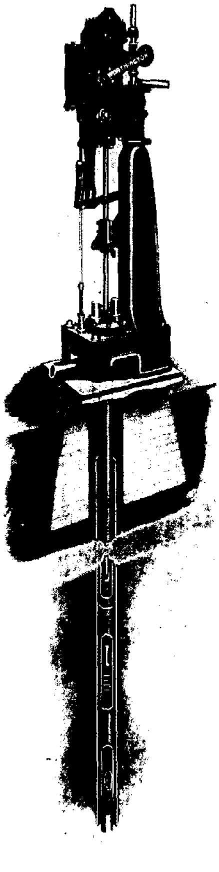


Fig 27.—Worthington vertical steam engine and single artesian or deep well pump, working in plain pipe of tube well.

a cost very much less than steam plant could possibly have run under similar conditions; these engines run on a low grade kerosine oil, the consumption of which is approximately three-quarters of a pint per brake horse-power per hour. Some of the other small sizes of well-known makes of oil engines run on crude oil and in the large sizes, engines of the Diesel type running on crude oil, generate power at an extremely low cost and occupy smaller space and require fewer attendants than steam plant of a corresponding power.

In districts where electricity at a favourable rate per unit is available, centrifugal pumps direct coupled to electro-motors, form a compact, silent, and highly efficient form of pumping plant, which can be run continuously with practically no attention. By this system a large number of tube wells may be pumped at a low cost and if the tube wells are arranged in the manner described for air lift pumping, then wiring is reduced to a minimum. The motor and pump must of course be within economical suction reach of reduced water level.

The following table shows approximate position of centrifugal pumps relative to spring level.

Size of pump.	Capacity in gallons per minute up to—	Size of tube well.	Height of pump above spring level in feet.	Head of depression when pump is working; according to subsoil.	Recommended maximum total suction in feet.
Inches		Inches			Feet.
3	140	$3\frac{1}{2}$	8 to 11	4 to 7	15
4	250	5	7 to 10	6 to 9	16
5	400	7	7 to 10	7 to 10	17
6	600	7	5 to 9	8 to 12	17
7	800	9	5 to 9	9 to 13	18

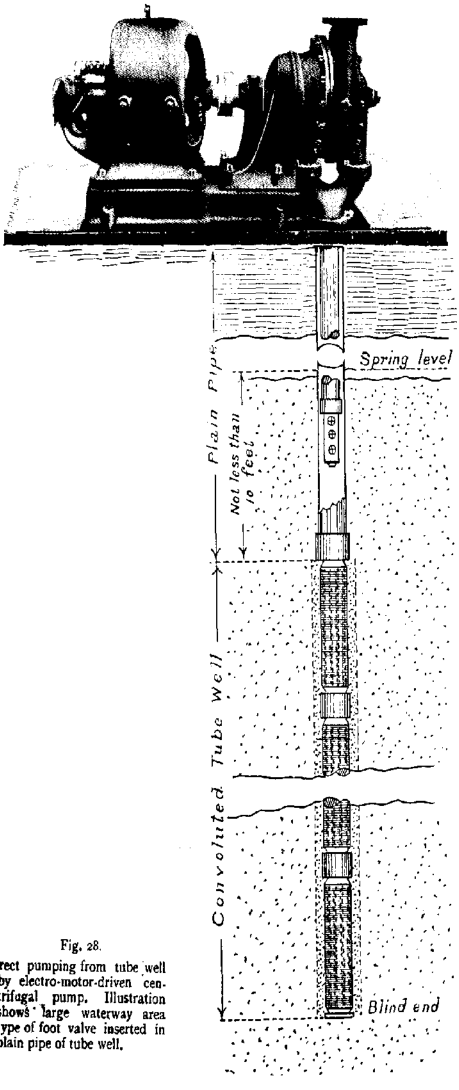


Fig. 28.

Direct pumping from tube well by electro-motor-driven centrifugal pump. Illustration shows large waterway area type of foot valve inserted in plain pipe of tube well.

Tube well pumps.

WHEN spring level is at such a depth that any of the methods already described for bringing the pump within its suction reach are impracticable on account of cost, etc., or when local conditions preclude the economical use of the air lift system, then it is necessary to employ a tube well pump. These pumps may be worked at any depth from 20 feet to 2,000 feet if desired, and in order to allow room for them the plain pipe from the tube well must be of large diameter: for example, a pump to deliver 34,000 gallons per hour would require to have a plain tube of 15 inches internal diameter attached to a 9-inch convoluted tube well which is capable of discharging 45,000 gallons per hour; and a pump delivering 10,000 gallons per hour would require to have a plain pipe of 9 inches internal diameter attached to a 5-inch convoluted tube well.

There are two methods by which the large plain tube can be fixed, the simplest method is to sink the original boring tube of a size sufficiently large to allow the large plain pipe to slip freely through it. The plain pipe is secured to the convoluted tube well with a reducing piece of the required size and lowered into the bore tube as previously described, sufficient plain pipe being added to reach to ground surface and then the original bore tube is withdrawn. Another method is to sink the original bore tube of a size sufficiently large to allow the pump to pass freely into it, for example, in the case of a pump for 10,000 gallons per hour, a bore tube of at least 9 inches diameter is sunk to the required depth and into this the 5 inches diameter convoluted tube well with say ten feet of 5-inch plain pipe attached is lowered. The bore tube is now withdrawn sufficiently to bring its lower edge level with the top of the convoluted tube: thus the bore tube overlaps the plain pipe attached to the tube well; the space between the bore tube and

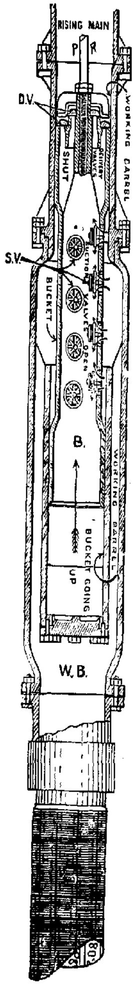


Fig. 29.
(P.R.)—Pump rod.
(D.V.)—Delivery valve.
(S.V.)—Suction valves.
(W.B.)—Working barrel.
(C.)—Tube well.

DETAILS OF ASHLEY'S PUMP.

plain pipe is then rendered watertight with a cement plug and the bore tube is ready to receive the pump, etc.

The pump barrels with the rising main are now lowered into the tube to a depth of ten to fifteen feet below spring level according to circumstances, the plunger with the plunger tubes or rods attached is next lowered into the pump barrel and the pump is ready for work. Pumps of this type are known as the "Ashley" pump, made by Glenfield and Kennedy Ltd., and the double acting artesian well pumps are made by the Worthington Pump Co., Ltd. Both pumps are double-acting thereby equalizing the load and, as all valves are attached to the bucket or plunger, they can be simply and expeditiously withdrawn when necessary, by raising the rods only. The "Ashley" pump is provided with an extremely ingenious arrangement for automatically balancing a varying load caused by a large rise or fall of water level in the bore tube.

Tube well pumps may be connected to any form of well head and driven in the ordinary way by steam, oil, electric power, etc. Fig. 30 shows a favourite type of steam drive for these pumps; the cylinder is arranged in such a way that it can be swung round, leaving the bore tube clear for withdrawal of the plunger for repairs, etc. Fig. 31 illustrates the double acting form of Ashley pump and it shows diagrammatically the general arrangement of pump, tube well, etc.

In cases where a larger supply of water is required than can be obtained from one tube well, two tube wells may be sunk at a distance of ten or twelve feet centres and worked by deep well pumps coupled to the one engine by bell cranks and connecting rods.

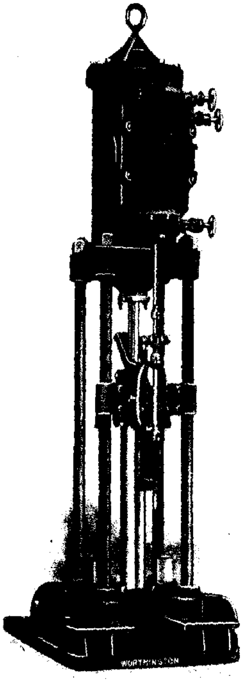


Fig. 30.—Swing type of steam drive for bore hole pumps, made by Messrs. Worthington and Co.

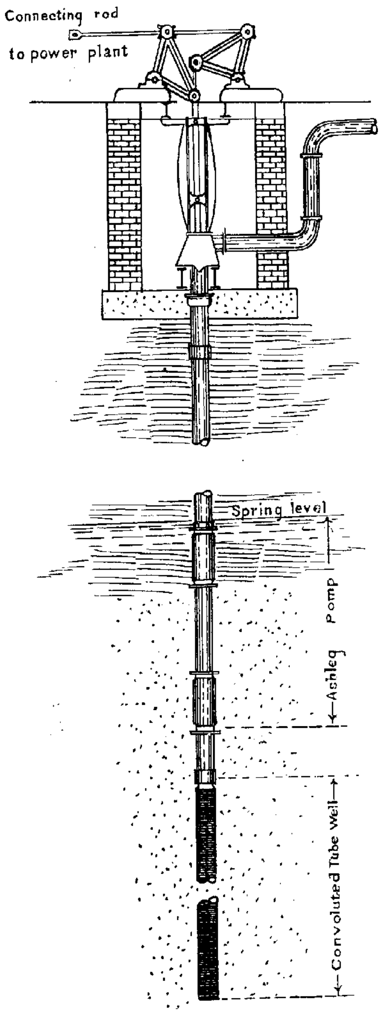


Fig. 31.—Double acting Ashley pump with bell crank links to rods.

EXCLUDING SURFACE WATER.

In many districts the surface water is brackish or otherwise unwholesome, while by continuing the boring to a greater depth a supply of good potable water may be obtained. When the brackish water is separated from the good water by an impermeable stratum of clay or rock, etc., it is a simple matter to prevent the surface water from flowing downward in the annular space surrounding the plain pipe of the tube well and entering the strainer portion of the tube well along with the good water. A fairly simple method of exclusion is as follows :—

Assuming that the boring is completed and the tube well ready to be lowered into position; the top of the convoluted tube well to be below the bottom of the mpervious stratum. An expanding plug is arranged on the plain pipe of the tube well, in such a position that when the tube well is lowered and resting on the bottom of the bore hole, the plug will be opposite the impervious stratum. A suitable plug can be made from an old inner tube of a large size pneumatic tyre, the tube is cut and cemented to a size which is to fit on the plain pipe of the tube well and is held temporarily in position by numerous bands of rubber, binding tape or sticking plaster, a small ring filed to an internal knife edge is secured to the plain pipe close to the plug and the rubber tube from the valve of the plug to the pump is looped through this ring. The tube well is lowered into position, care being taken to pay out sufficient of the rubber air tube as the tube well is lowered. The bore tube is then withdrawn until its lower edge is just above the plug; the plug is next inflated, pressing hard on the plain pipe of the tube well and on the impervious stratum, a Portland cement plug is then poured in on the top of the rubber plug, a few sharp jerks on the rubber air tube will suffice to free it by cutting through

on the knife-edged ring, and the bore tube is withdrawn, leaving a solid cement plug bridging the space between the plain pipe and the impervious stratum.

CONE OF DEPLETION.

WHEN several tube wells have to be sunk for a water supply, it is desirable to keep them as close as possible without the one tube interfering with the supply from another. Observations of the cone of depletion have been made in moderately fine sand for 3½ inch tube wells discharging 5,000 gallons per hour and the points at which the cone of depletion curve cuts a horizontal plane *six inches below* the normal spring level are given in the following table :—

Head of depression in feet.	Distance from tube at which cone cuts six inches below water table.	Minimum distance apart of tubes.
2	31	62
4	47	94
6	62	124
7	70	140
8	79	158
10	96	192
12	118	236

Within safe working limits the yield of a tube well is similar to an ordinary percolation well in so far that the discharge increases directly as the head of depression and therefore when once the water level in any well has been lowered it theoretically will take infinite time to recuperate the last few inches, for this reason it is considered sufficient to place ordinary percolation or tube wells at such a distance apart that their cones of depletion intersect at a point six inches below spring level.

There are occasions when a fixed supply of water is required at one point and the water-bearing stratum is of an insufficient depth to allow the full length of the

required size of tube well being used ; in such cases two or more tube wells may be sunk at a distance of a few feet from one another and the required supply obtained: in such an arrangement the depletion cone of the one tube interferes seriously with that of the other and the head has to be increased somewhat beyond that which would be required to yield the proportionate supply from one tube only.

For example, a supply of 20,000 gallons per hour may be obtained at one point from a water-bearing stratum which is only 50 feet deep, by sinking three 5-inch convoluted tube wells each 42 feet long, the average yield of each tube being under 7,000 gallons per hour, the head required being quite 25 per cent. greater than when drawing 7,000 gallons per hour from one tube only. In such an arrangement the pump suction pipe may be branched to each tube through a special casting, or a simpler and more convenient method, is to sink the tubes in one pump sump of eight or ten feet diameter.

TESTING WELLS AND TUBE WELLS.

THE simplest and also the most accurate method of gauging the yield of any well is the recuperative test. The method of procedure is as follows. Assume that a percolation well is to be tested, the normal spring level being 20 feet below ground surface and the well is sunk in a soil the critical velocity of which permits of a head of only 7 feet. The depth from a fixed mark at the top of the well to water level is carefully measured and reads say 20 feet, the pump is started and water pumped down to seven feet six inches below the depth recorded, the pump stopped and the exact time of stoppage of the pump noted when the depth from the fixed mark is 27 feet six inches, the time is again recorded when the water rises one foot or to 26 feet 6 inches and again

when water has risen a second foot to 25 feet 6 inches and so on for every foot, up to 20 feet 6 inches. The difference between any two consecutive time readings gives the actual time the water took to rise that one foot and any slight inaccuracy in one reading is balanced in the next reading. If the time reading at 24 ft. 6 in. is 10 hours 14 minutes 30 sec. and the reading at 23 ft. 6 in. is 10 hrs. 29 min. 30 sec. the difference is 15 minutes for a head of 4 feet, the yield being 78·5 cubic feet* in 15 minutes or 1,962½ gallons per hour, and similarly for each foot of head. It will be observed that by this method the last reading will be the time taken to rise from 21 feet 6 inches to 20 feet 6 inches; this gives the yield of the well under a head of one foot. This method of counting the head as the mean depth of each foot of rise is considered more accurate than when the head is considered the lower or higher reading; as obviously when the water level is at say 24 feet 6 inches, the well is yielding a greater quantity than it is by the time the water reaches 23 ft. 6 in. Theoretically, a more accurate observation would be made by considering the head to be four inches above the lower reading so that to measure discharges at even feet, the well should be pumped to a head of 7 feet 4 inches and the time taken as water rises to 6 ft. 4 in., 5 ft. 4 in., and so on; in this way the last time reading to be taken would be when the water level is four inches below normal spring level, but as it is the last few inches which take an infinite time to recuperate it is customary to neglect six inches and consider one foot as the head for a recuperation from 1½ feet to ½ foot.

Tube wells which have been sunk in existing wells or in pump sumps are tested precisely as above, in the former case the existing well should be tested prior to sinking the tube well if the well is to remain unsealed

* This assumes a well of 10 feet diameter.

and if the yield of the tube only is wanted, in which case the yield of the existing well is deducted from the combined yield of well and tube well. With large tube wells sunk in pump sumps, recuperation is extremely rapid and considerable care is required in timing and in reading the depths. A light measuring rod or tape secured to a large float is a convenient method, the tape being kept taut by passing it over a pulley and hanging a weight sufficient to balance the float, a pointer fixed to the well head will serve as the fixed mark ; as the tape rises with the water the depths can be called out and the time noted in seconds and fractions, on a stop watch.

When tube wells are sunk for direct pumping, accurate recuperation tests are impossible, as the water simply flashes up the plain tube, the simplest method in such cases is to pump as steadily as possible for a time, passing all water from the pump over a rectangular or V-shaped notch, the head being measured by a float and cord, in a small tube alongside the tube well; or the head may be recorded by fixing a vacuum gauge on the suction pipe. This latter method is seldom accurate as so many allowances for temperature, level, and atmospheric pressure, etc., have to be made. If two good observations are made in this way with the pump working at half speed for the second, the yield is obtained for two heads and as the discharge varies directly as the head the remaining points can be calculated.

Some engineers rely on the discharge of the pump in preference to measuring by passing the water over a notch, but this generally leads to results far from accurate: the pump speed may vary considerably, valves may be out of order, joints may not be tight, or many causes may go to produce a discharge very different to that which the pump is supposed to be yielding.

THE END.